Canada Foundation for Innovation
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Project Module
New Initiatives Fund (NIF)

Date submitted (dd/mm/yyyy): **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Language of application:

☒ English ☐ French

Applicant institution:	The University of Winnipeg
Designated Project Leader	
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Project Funding

Total project cost:	$10,900,000
CFI Request ($):	$4,225,000
CFI Request (%):	38.76 %

Proposal focus:	Research proposal
Research discipline/field	
Primary:	PHYSICS
Primary sub-discipline:	Nuclear Physics
Secondary:	PHYSICS
Secondary sub-discipline:	Particle Physics
Tertiary:	PHYSICS
Tertiary sub-discipline:	Weak Interactions
Area of application	
Primary:	Other research
Secondary:	

Keywords: ultracold neutrons, spallation, neutron physics, neutron moderators, surface nanoscience, materials science, electric dipole moments, weak interactions, beta decay, gravity

Signature of the applicant institution: It is agreed that the general conditions governing the partner contributions, and the use of CFI funds as outlined in the Institutional Agreement and the CFI Policy and Program Guide apply to the infrastructure project outlined in this application. These conditions are hereby accepted by the administering institution.

Name: ______________ **Signature:** ______________ **Date:** ______________

President/CEO of the institution (or authorized representative)

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Collaborating Institutions

The following eligible institutions agree that the general conditions governing the partner contributions and the use of CFI funds, as outlined in the Institutional Agreement and in the CFI Policy and Program Guide, apply to the project outlined in this application and are hereby accepted by each institution.

Institution: University of Manitoba

Name (CEO, President or authorized representative):

Signature: ____________________ **Date:** ____________________

Institution: Simon Fraser University

Name (CEO, President or authorized representative):

Signature: ____________________ **Date:** ____________________

Institution: University of Northern British Columbia

Name (CEO, President or authorized representative):

Signature: ____________________ **Date:** ____________________

Institution: TRIUMF

Name (CEO, President or authorized representative):

Signature: ____________________ **Date:** ____________________

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Project Summary

We propose the construction of the world's highest density source of ultracold neutrons (UCN), the Canadian Spallation Ultracold Neutron Source (CSUNS). The project would be a collaborative effort between Canada, Japan, and the US.

A window of opportunity exists to capitalize on the successes of Japanese collaborators developing new technology to produce UCN, allowing the Canadian project to surpass other proposed sources elsewhere. The UCN source would be located in Canada at TRIUMF, Vancouver, BC. This location is ideal because of the high-intensity high-energy proton beam available, 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 project 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. Being the most intense source of ultracold neutrons in the world, the source would attract many international users to Canada.

The UCN source technology is a superthermal source based on the 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 and 20 K cold moderators. The resultant cold neutrons are down-scattered by phonons in superfluid 4He (He-II) to UCN energies. UCN are transmitted through guide tubes to experiments.

The experiments that would be conducted initially at CSUNS would be measurements of the neutron lifetime, of neutron energy levels in the earth's gravitational field, and of the neutron electric dipole moment.

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. In-kind contributions to the project would be supplied by a combination of TRIUMF (NRC) and Japanese sources.

The fundamental neutron physics experiments that would be conducted using the UCN source have been identified as the highest priority experiments for this field. The completion of these cutting-edge experiments would represent a long-term program for subatomic physics in Canada. Since the Canadian project would produce the highest density of UCN, Canada would thereby lead the rest of the world in this field. Initially, the program would focus on the following suite of experiments:

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Project Summary

* A precision measurement of the neutron lifetime. The neutron lifetime is a critical parameter in astrophysics in that the neutron lifetime determines the abundances of light elements in our universe. It is also a critical parameter for accurate determinations of a parameter of the standard model of particle physics V_ud. An accurate measurement of this parameter is important for searches for new physics beyond the standard model.

* Precise spectroscopy of the quantized energy levels of neutrons confined above a mirror in the earth's gravitational field. This experiment would test theories of modifications to gravity, predicted by string-theory motivated models involving extra dimensions.

* A search for a non-zero neutron electric dipole moment. Such an experiment aims to search for an explanation of the predominance of matter over antimatter in the universe. A non-zero value found at the current level of sensitivity would also indicate new physics beyond the standard model.

None of these projects can currently be completed in Canada because of a lack of the appropriate infrastructure. The project would therefore represent a new direction in subatomic physics in Canada. The world-leading facility that would be created would increase involvement in Canada's scientific program from new users outside Canada. Many of the other collaborators listed on the proposal who are from outside Canada have never done so before. Their interest in the Canadian project is due to the fact that they want to be involved in this world-leading facility. The Japanese and U.S. collaborators, who are from prestigious institutions in those countries, are already asking for time to use the facility, and would either lead or otherwise be involved in the cutting-edge experiments listed above.

The technology used in the creation of the infrastructure is also state of the art. Unique technologies used in the ultracold neutron source are cryogenics, vacuum technologies, nuclear instrumentation, RF technology, and superconducting technology. Many of these technologies are common to the medical field, and there is typically a large cross-over in personnel. Neutron transport issues in the UCN source are similar to those encountered in the design of future nuclear reactors, and similar to the modern-day use of radiation-related technologies to safety and to advanced manufacturing methods. Acsion Industries, a Manitoba business with expertise in this area, has therefore joined the project and has provided an in-kind contribution to help study these issues.

Over the period of construction and operation of the infrastructure, the project will contribute to the training of a large number of undergraduate students, graduate students, and postdoctoral scholars. These highly qualified personnel would be trained in the use of the aforementioned technologies, and in the science of fundamental

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Project Summary

physics. Such personnel therefore receive training in some of the highest technologically-advanced science in the world. They are usually highly motivated individuals who can succeed in almost any technological field in today's knowledge-based society in Canada.

The project therefore satisfies the People, Knowledge, and Entrepreneurial Advantages mentioned in Canada's S&T priorities. It also promotes world-class excellence by targeting an area of strength in basic research.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Institutional Priority and Commitment

Criterion Standard:

The proposed project is of strategic importance to the institution. The institution has made and will continue to make tangible and significant commitments in support of this area of strategic priority. These commitments are, or will be, of direct benefit to the proposed project, including the attraction and retention of the best researchers.

Each of following aspects must be addressed:

1. Describe the significant support that the institution has provided to this area of research (e.g., institutional resources committed to capitalize on the proposed infrastructure, the creation of new research positions, or research chairs in these areas, etc.).
2. Describe the significant and tangible contributions that the institution will make to the current and on-going needs of the proposed project.
3. Explain why this project is important to the fulfillment of the institution's strategic research plan.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Quality of the Research or Technology Development

Criterion Standard:

The research opportunity is timely and has the potential to lead the breakthroughs in research or technology development. The proposed research or technology development is innovative and at the leading edge internationally.

Each of following aspects must be addressed:

1. Describe the proposed research or technology development activity and the potentially transformative and innovative aspects of this endeavour.
2. Explain why it is important to pursue the proposed research or technology activity at this time.
3. Explain how the proposed research or technology development activity complements or differs from comparable research or technology development being conducted nationally and/or internationally.

1. Proposed Research and its Transformative and Innovative Aspects

1.1 Introduction: Ultracold Neutrons and Sources

Ultracold neutrons (UCN) are neutrons of such remarkably low energies that they are totally reflected from the surfaces of a variety of materials. Hence, UCN can be stored in bottles for long periods of time, whereas higher-energy neutrons would either pass through or be captured in the walls of the bottle. Typically, UCN have kinetic energies that are less than 300 neV. Correspondingly, UCN are strongly affected by various fields, such as the Earth's gravitational field, and by strong magnetic fields (7 T).

The difficulty encountered historically in producing UCN has been to liberate them from atomic nuclei, and then to efficiently and effectively cool the neutrons without suffering large losses. In the past decade, a new method of cooling the neutrons has come to light. Based on a technique from condensed matter physics, sources that employ this method of cooling are known as superthermal sources.

The advent of superthermal sources of UCN is just now beginning to transform the landscape of fundamental neutron physics. These sources have now have now demonstrated UCN densities surpassing all previous sources. Sources are being proposed at various facilities in the world. Our proposal is to construct The Canadian Spallation Ultracold Neutron Source (CSUNS). As will be explained in section 3, this project would exceed the capabilities of all planned future UCN sources worldwide. The source would provide the highest density of UCN ever achieved, and would enable the most precise measurements in fundamental neutron physics ever conducted.

1.2. Proposed Research Activity at CSUNS

Quality of the Research or Technology Development

Given the new technology that has led to this breakthrough in UCN production, a variety of new UCN experiments can be envisioned that can now be conducted with higher precision than ever before. We have considered a variety of physics experiments that could be done with the Canadian source, and have decided to focus in the short term on the three experiments with highest scientific priority for the field:

* a precise measurement of the neutron lifetime,

* characterization of the recently discovered UCN quantum states in the Earth's gravitational field, and

* a search for a non-zero neutron electric dipole moment.

Each project has its own physics interest and timeline, so that, in time, a series of UCN experiments would be performed at the CSUNS facility.

The funding that we are requesting in this proposal is for the UCN source, CSUNS, alone. The experiments themselves are significant undertakings, requiring their own funding, which would be sought from a combination of NSERC, Japanese, U.S., and other international sources once the infrastructure project (CSUNS itself) has been funded by CFI. These cutting-edge experiments, each with their own physics interest in searches for new physics beyond the Standard Model, justify the construction of CSUNS.

In this spirit, we now briefly describe the physics motivation, timeline, and the current status and collaborators involved in each experiment, assuming the superthermal UCN source (CSUNS) were to exist. (We return to the discussion of the UCN source itself in section 3, in the section "Need for the Infrastructure", and in the "Budget Justification" module.)

1.3 Neutron Lifetime

Precise measurements of the neutron lifetime are of physics interest primarily for two reasons:

* The neutron lifetime is an essential parameter for Big-Bang Nucleosynthesis (BBN) calculations, and is currently the dominant uncertainty for accurate BBN predictions [1].

* The neutron lifetime can be used, in combination with measurements of angular correlations in neutron decay, to extract the CKM matrix parameter V_ud. V_ud is the most precisely measured, large parameter in the CKM matrix and is useful for a variety

of tests of the unitarity of the CKM matrix. Lack of unitarity would signify new physics beyond the standard model. Currently, V_ud is most precisely determined from superallowed nuclear decays. UCN lifetime experiments offer an independent check of the nuclear extraction, free of nuclear corrections.

Figure 1 (in the attached pages) displays the current status of the CKM matrix element V_ud. It also displays the current status of previous experimental results for the neutron lifetime. There exists a seven sigma discrepancy between the most recent precise measurement of the neutron lifetime (878.5 +/- 0.8 s, [2]), and the average of all previous measurements (885.7 +/- 0.8 s, [3]). The most recent precise measurements have been performed in traps formed by the mean Fermi potential of material walls [4, 5] or material walls in combination with gravity [2]. The largest systematic uncertainties in these experiments arise due to effects of the interactions of the UCN with the material walls of the trap. At TRIUMF, a magneto-gravitational trap would be used to confine the neutrons, thus removing such effects. Similar projects with magnetic trapping of UCN have been discussed in the context of experiments at LANL [6], and elsewhere [7, 8, 9]. Our project would build on preliminary research performed at LANL, achieving better precision at CSUNS because of the increased density of UCN that would be available there.

The new magnetic trap experiments have identified an important new systematic effect specific to magnetic traps: marginal trapping of UCN with energies larger than the trap depth. These quasi-trapped UCN can escape from the trap with timescales similar to the neutron lifetime, potentially giving a large systematic effect. These UCN must therefore be removed from the trap rapidly so that measurements of the UCN lifetime can be performed. The LANL trap design deals with this problem by introducing chaotic neutron orbits within the trap so that the quasi-trapped UCN rapidly sample their allowed phase space and escape. New ways of cleaning these UCN from the trap will be discovered at LANL, thereby making the statistical uncertainty dominant. The higher UCN density available at CSUNS would then be used to reduce the statistical uncertainty.

1.3.1 Neutron Lifetime Experiment for CSUNS

The magneto-gravitational trap from LANL [6] is designed to contain field-repelled neutrons, i.e., neutrons in a positive-energy eigenstate of the spin-field interaction. Figure 2 (found in the attached pages) shows the proposed trap for CSUNS, which would be based on the LANL design. The design calls for an open-top magneto-gravitational bowl trap with two independent magnetic-field-generating components: high-strength neodymium-iron-boron (NdFeB) permanent-magnet (PM) Halbach arrays [10, 11] that form the open-top bowl-shaped trap surface, and a enveloping set of current-carrying window-frame coils outside of the bowl.

The PM arrays produce a field in the trap volume that is approximately 1 T at the surface and falls off exponentially in normal distance from the PM array surface with a characteristic length of about 1 cm; the PM field is the main confining field of the neutrons. The effective trap volume is 0.6 cubic metres. The window-frame coils produce a field of approximately 0.05-0.1 T that is everywhere perpendicular to the dominant component of the PM-array field and performs two essential functions: first, to guarantee that the trapped neutrons never encounter a zero field magnitude, and second, to guide the decay electrons to the detectors at the two ends of the trap. Under these conditions, neutrons with low enough kinetic energy are perfectly reflected from the field near the trap surface, and if their kinetic energy at the bottom of the trap is small enough to not exceed the trap height, they would stay in the trap for an effectively infinite time, except for their natural decay.

Neutrons are fed into the trap with a mechanically operated trap door at the bottom of the trap. The upper surface of the trap door is covered with a Halbach linear PM array in such a way that when the door is closed, the combination of the trap-door PM array and the PM arrays on the trap surface around the door opening forms a continuous Halbach array without gaps. The trap door will be opened and closed by an actuator below the bottom of the trap. Calculations have shown that forces on the trap door are manageable from the point of view of the mechanical actuator (on the order of about 800 N in the worst-case position).

Quasi-trapped neutrons are removed during the filling/cleaning phase of operation by a neutron-absorbing cleanout surface that is lowered to a height that is approximately 5-10 cm below the top of the bowl. The cleanout surface is then withdrawn to a level above the top of the trap after the trap door is closed and before counting of neutron decays for the lifetime measurement is started. In order to facilitate removal of quasi-trapped neutrons, the bowl has shallow inclination angles on one side and at both ends that force neutrons to acquire a large vertical velocity component at some point along their trajectories and then reach a sufficient height to strike a cleanout absorber. Moreover, chaotic orbit behavior is induced by ripples in the permanent-magnet field.

A prototype of the trap is under construction at Los Alamos. Individuals from that collaboration have joined the TRIUMF UCN effort: J.D. Bowman, B. Filippone, T. Ito, and B. Plaster. Since it is already in development, and would have a relative short running time, the neutron lifetime experiment is a candidate for the first fundamental physics experiment at CSUNS.

A measurement of the neutron lifetime with precision <1 s, but performed in a magnetic trap free of the systematic uncertainties which hinder material traps, would be a very exciting achievement for this field. Such an experiment could be completed at CSUNS in the 2013 timeframe. The superior UCN density achieved there would be instrumental in achieving the < 1 s statistical error bar required.

1.4 Gravity Levels Experiment and Plans for CSUNS

Recently, a group at ILL has successfully observed the quantization of the energies of neutrons confined above a UCN mirror in the Earth's gravitational field [12]. The experiment is an interesting application of quantum mechanics to micron-sized quantum states. The experimental result has been used to place limits on modifications to the short-range (10 micron) behavior of gravity. The result therefore has impacted theories involving micron-scale extra dimensions. The result has also been used to constrain axion models [13].

The same group at ILL is mounting a more advanced experiment (the GRANIT experiment) where they would attempt to excite resonant transitions between gravitational levels in a UCN bottle, achieving better resolution in the level spacing and hence placing tighter constraints on theories.

These experiments are limited in their scope by the UCN density available at ILL. TRIUMF therefore would have a distinct advantage for a new experimental effort. Additionally, this is a relatively new avenue of research in the UCN community, and much progress is being made rapidly. A timely experiment at TRIUMF would have a large impact on the field.

The experiment would take roughly one year to complete. The design of this experiment and the main detector are underway in Japan. This being the case, and owing to the short run time for the experiment, this experiment is therefore also a candidate to be one of the first fundamental physics experiments to be conducted using the UCN source at TRIUMF.

1.5 Neutron Electric Dipole Moment (n-EDM)

Electric dipole moments for fundamental particles are forbidden by time-reversal symmetry. The small amount of CP violation in the standard model leads to very tiny EDM's (for the neutron EDM, 10^-31 e-cm). However, new sources of CP violation beyond the standard model are required to account for the observed baryon asymmetry of the universe (BAU). In many models of physics beyond the standard model, extra sources of CP violation are often present. Such models often naturally generate neutron EDM's at the 10^-27 e-cm level [14]. The current experimental limit on the n-EDM is d_n < 3x10^-26 e-cm [15]. The next generation of experiments at ILL, PSI, and SNS aim to constrain the n-EDM to the 10^-27-10^-28 e-cm level. The aim of an experiment at TRIUMF would be at the 10^-28 e-cm level.

1.5.1 Experimental Principle

Neutron EDM measurements use Larmor precession under a static magnetic field and a static electric field. The effect of an EDM is extracted upon electric field reversal. The phase shift that would be induced by a non-zero electric dipole moment in the electric field is measured by means of neutron polarimetry and hence the neutron electric dipole moment d_n is extracted.

The statistical uncertainty on the EDM is minimized for the largest number of neutrons sampled. For experiments where the experimental volume is smaller than the UCN source volume, it is UCN density that is therefore the most important factor, and CSUNS will be the world leader in UCN density.

Systematic errors that reverse sign with E reversal must also be carefully controlled. Systematic effects arise due to magnetic field instability, due to changes in magnetic field induced by leakage currents, and due to motional magnetic fields in the rest frame of the neutron. To correct for magnetic field instabilities, a "comagnetometer" is used. The comagnetometer is simply an atomic species which samples the same fields experienced by the neutrons.

In the highest precision experiments, an additional systematic effect must be considered which arises from magnetic inhomogeneity and relativity: the recently discovered "geometric phase effect" [16, 17, 18]. This effect arises due to a combination of magnetic field inhomogeneity and neutron motion effects for neutrons confined to a trap. Future experiments must be careful to take into account this effect in their design, which any effort at CSUNS would certainly do.

1.5.2 Previous n-EDM experiments

In the previous ILL experiment, UCN were confined in a 50 cm diameter, 12 cm tall cell, in a 1 uT magnetic field and a 12 kV/cm electric field. The result for the upper limit on the n-EDM was d_n<3x10^-26 e-cm, with the precision limited by statistics. The UCN density in the EDM cell was 0.7 UCN/cc.

A co-magnetometer of 199Hg was used; hence magnetic field fluctuations were well normalized. Systematic errors associated with E reversal, were controlled to better than 10^-27 e-cm. The false EDM due to the geometric phase effect was characterized as a function of the field gradient so that the systematic error could be reduced.

1.5.3 Future n-EDM Experiments

A broad variety of novel, cutting-edge techniques are being pursued for the next generation of n-EDM searches. Some of the proposed techniques have not been proven experimentally at this time. An n-EDM experiment at CSUNS would build on research completed by the most successful of the three major experimental groups pursuing measurements at this time. We now review these future efforts which will first occur elsewhere.

A new EDM measurement at ILL ("CryoEDM") will use a double cell (24 cm diameter and 4 cm height for each cell) with UCN of density 1000 UCN/cc. The cell will reside in a superfluid helium bottle. In this way, an electric field can be applied with lower leakage current. A superconducting magnetic shield will minimize systematic errors associated with field instability. For one cell, an electric field of 40 kV/cm will be applied while, for the other cell, no electric field will be applied. Neutrons in the second cell will hence be used as a magnetometer, but no co-magnetometer will be present in the measurement cell in the initial phase of the experiment.

A group using the future UCN source at PSI is also preparing an n-EDM experiment. They will carry out a preliminary measurement at ILL with the previous EDM cell of ILL, and then a measurement of 5x10^-27 e-cm at PSI from 2009 to 2010. The UCN density in the EDM cell will be 1000 UCN/cc. The experiment will employ several magnetometers outside the EDM cell. They are aiming for a precision of 5x10^-28 e-cm in measurements from 2011 to 2015 [19].

A new n-EDM measurement employing a unique experimental technique is also in preparation for the SNS. A cold neutron beam from the SNS will impinge upon a volume of superfluid 4He creating 150 UCN/cc. The n-EDM measurement will be conducted in the same volume. A small amount of polarized 3He introduced into the superfluid 4He will act as a co-magnetometer. A "dressed spin" technique will be used, where the neutron spin precesses with the same frequency as the 3He spin. The neutron spin will be aligned with the 3He spin, so that essentially no neutron captures will occur. Any small effect caused by a non-zero EDM will modulate the capture rate on E-reversal. The capture rate will be measured by sensing scintillation light produced by the capture products. The goal precision is 10^-28 e-cm. Many technical challenges must be overcome for the experiment to be successful. The geometric phase effect for the 3He magnetometer can be large compared with 199Hg, but is mitigated because of

Quality of the Research or Technology Development

collisions with the surrounding 4He [17, 18]. Measurements at the SNS will begin in 2013 [20].

1.5.4 Plans for n-EDM at CSUNS

We envision that any n-EDM effort at TRIUMF would occur after the completion of this new round of n-EDM measurements at ILL, PSI, and SNS, in the time frame of 2015 and beyond. It is difficult to say at this time which of these differing techniques would be shown to be the most successful by that time, and which would be best able to use the increased statistical precision which would be possible at TRIUMF. One possible scenario for the initial and fast completion of an EDM project at TRIUMF would be to simply move one of the devices from e.g. ILL or SNS, similar to the initial PSI strategy. To take advantage of the higher density at TRIUMF for systematic error reduction, a new and significantly smaller measurement cell would need to be designed.

This section is continued in the attached pages.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Researchers (Principal Users) *

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Researchers (Principal Users) *

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Researchers (Use of the Infrastructure)

Criterion Standard:

The principal users of the infrastructure are experts in the relevant research or technology development domain. The research group has the expertise and experience to lead the proposed endeavour.

Each of following aspects must be addressed:

1. Demonstrate that the research group is comprised of highly accomplished researchers and may also include new researchers who have demonstrated potential for excellence and leadership in all the proposed field(s), or experts in technology development who have been recognized for their accomplishments. If any principal users are to be recruited, describe the recruitment plan.
2. Explain how each principal user will use the infrastructure to contribute to the proposed research or technology development.
3. Describe the existing or emerging collaboration and complementarity among the principal users.
4. Demonstrate that the principal users/team have the research or technical expertise to capitalize on the use of the requested infrastructure.

1 Accomplishments and Expertise of Principal Users

The principal users listed on the proposal are Canadians who all have demonstrated track records of significant achievements in experimental subatomics physics. They are well-respected in the Canadian subatomic physics community and internationally. The one Japanese collaborator listed on the proposal is Y. Masuda, who is a well-known researcher in neutron physics worldwide.

The project leader, J. Martin, was a driving force behind the construction of the UCN source at Los Alamos National Lab (LANL) and was a leader in the experiments subsequently conducted there. The LANL UCN source currently holds the world record for highest UCN density achieved at 145 UCN/cc. This has served as the first and to date most impressive validation of the superthermal technique that we will use to produce UCN. Also, he has been a leader in detector development in the UCNA project at LANL, where his research has focused on the development of detectors for the UCNA experiment and on the study of systematic effects due to backscattering of low-energy electrons from the surfaces of detectors. Prof. Martin performed research at two of the most prestigious universities in the U.S.: MIT, where as a graduate student he performed the first extraction of the gluon contribution to the proton's spin from high transverse momentum pions; and Caltech, where as a postdoctoral fellow he completed the LANL work and experiments in electron scattering on the contribution of strange quarks to the nucleon form factors. He is currently leading two major detector projects in the Q-weak experiment at Jefferson Lab.

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Project title: Canadian Spallation Ultracold Neutron Source

Researchers (Use of the Infrastructure)

The research group of J. Martin, J. Birchall, C. Davis, M. Gericke, E. Korkmaz, S. Page, and W. van Oers has successfully completed difficult parity-violation experiments at various labs. With recent arrival of new faculty members (J. Martin and M. Gericke) the group has renewed its interest in fundamental physics with UCN and CN. The group is currently involved in a large project to make the world's most precise determination of the weak mixing angle from e-p elastic scattering at Jefferson Lab (the Q-weak experiment) which will be installed next year. Though these Canadians and their group represent only 10% of the Q-weak collaboration, they are arguably the most well-known and effective group contributing to the project. This includes leadership since S. Page is the spokesperson of the collaboration.

M. Gericke, S. Page, and J. Martin are leaders in future experiments at the SNS (Spallation Neutron Source, Oak Ridge, TN), as well, primarily neutron beta-decay and parity-violating neutron hadronic weak interactions. M. Gericke, in particular, is the spokesperson of an experiment to measure parity-violating capture of neutrons on 3He. He also serves on the executive committee of the npdgamma experiment.

J. Martin and M. Gericke both have successfully obtained funding from the CFI LOF for detector fabrication and testing facilities at their respective universities. Infrastructure for these laboratories will be used to support detector fabrication for the future experiments at CSUNS.

J. Birchall, C. Davis, S. Page, and W. van Oers have been involved in experiments at TRIUMF to measure medium-energy neutron scattering from light nuclear targets to study the strong force.

The group also has demonstrated a strong commitment to service in the scientific community. S. Page is currently serving as president of the Canadian Association of Physicists. W. van Oers currently represents Canada on several high-profile subpanels of the International Union of Pure and Applied Physics. Both have served on the Grant Selection Committee for NSERC Subatomic Physics (GSC-19).

The group has been ameliorated significantly by two other researchers well-known in the Canadian community.

M. Hayden is a leader in UCN production in superfluid He and has recently authored a paper in PRL on the characterization of 3He impurities in superfluid 4He. This paper is related to the development of the SNS n-EDM project. He is very well-respected in the UCN community for these more recent achievements. He is also regarded as a world's expert on low-field NMR techniques and on novel magnetic field sensors (SQUID's) used in such experiments. He is currently a collaborator on the ALPHA experiment at CERN whose goal is to perform the first trapping of antihydrogen for spectroscopy.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Researchers (Use of the Infrastructure)

L. Buchmann, has been the main proponent of far-future experiments and has demonstrated the potential use of this UCN source as a free neutron target. He is most well-known for his research on nuclear structure, nuclear astrophysics, and fundamental symmetries in nuclei. He is currently a collaborator on the DRAGON and TUDA projects at TRIUMF.

There is also a great deal of expertise available at TRIUMF. The laboratory clearly has the capability to construct the proposed source, and the commitment of TRIUMF has been demonstrated by substantial contributions to the project. Future hires of new scientific staff would be made at TRIUMF in the area of fundamental symmetries, and such personnel would conduct research using both CSUNS and the TRIUMF ISAC project. We note a large degree of complementarity between the two projects.

Y. Masuda is the leader of the UCN source development project in Japan. He is a well-recognized researcher in the field of neutron physics. In the past several years he has dedicated all his research power into his successful and published technique of coupling a superfluid 4He UCN source to a spallation-driven target. It is his demonstrated source that will form the foundation for the CSUNS project. He is also well-known for his ground-breaking work in fundamental T and P violating processes in nuclei, and in neutron-nucleus interactions.

2 Contributions of Principal Users to the Proposed Research

Each principal user has already contributed to the development of the physics experiments and facility case for CSUNS and will continue to do so into the future. Once the project is underway, the collaborators will dedicate themselves to the successful completion of the neutron lifetime experiment. Y. Masuda, M. Hayden, and J. Martin would also perform the n-EDM development work that would be conducted simultaneously. The principal users are also involved in the management structure of the project, as will be discussed in the "Management" section.

3, 4 Existing and Emerging Collaborations, Complementarity, and Technical Expertise

The existing CSUNS collaboration (including other users) is expected to grow if funds are granted by CFI. At that time, more individuals across the world working on similar projects would be invited to join the project.

The collaboration already has a great deal of complementarity among its principal users, in a variety of aspects such as the point in their respective careers, to the topics studied in their established research topics. In particular we note the expertise of M. Hayden in condensed matter physics, has a detailed understanding of the

Researchers (Use of the Infrastructure)

basic physics mechanisms behind the operation of the UCN source. This expertise, coupled with Y. Masuda's and J. Martin's practical experience in constructing UCN sources, combined with the expertise of the other principal users in conducting difficult subatomic physics experiments and neutron physics experiments has led to a vital and active collaboration with the required technical expertise to complete the infrastructure project and the research to be done there.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Need for the infrastructure

Criterion Standard:

The infrastructure requested is appropriate and essential to support the proposed activities. It will establish or enhance a unique and important institutional capability in an area of leading edge research or technology development.

Each of following aspects must be addressed:

1. Explain why the requested infrastructure is appropriate for the proposed research or technology development.
2. Explain why the proposed research cannot be supported using existing infrastructure.
3. Describe the availability of similar infrastructure within the institution, the region, the country, and/or internationally and address any issues of accessibility, complementarity, duplication, and sharing.

1 Appropriateness of the Requested Infrastructure for the Proposed Research

1.1 Introduction

The fundamental physics experiments envisioned for CSUNS (described in "Quality of the Research") all have one feature in common: they are currently limited by the statistics achievable in the experiment. For this reason, it is the achievement of the highest possible densities of UCN which is the most important factor.

The UCN source technology proposed is a superthermal source based on downscattering of cold neutrons (CN) by phonons production in superfluid 4He [23]. Fig. 4 (in the attached pages) displays a schematic diagram of the proposed UCN source.

Neutrons are liberated by the highly efficient process of proton-induced spallation from a tungsten target using the 500 MeV TRIUMF proton beam. It is the combination of these two features (spallation, combined with 4He technology) that sets the CSUNS project apart from the all other sources worldwide. This source technology has been developed by Y. Masuda's group in Japan. Using a prototype source at the Research Center for Nuclear Physics (RCNP) Osaka, a UCN density of 10 UCN/cc has already been achieved.

It is primarily the superior proton beam power in Canada (at TRIUMF) that would lead to the creation of truly high densities of UCN. Since UCN production scales with beam power, this results in a predicted increase in UCN density by a factor of 51 when operated in Canada. This, coupled with incremental gains from changes in geometry and UCN guide technology resulting in an additional factor 20 gain, will give rise to UCN densities exceeding 10,000 UCN/cc at CSUNS.

Applicant institution: The University of Winnipeg	**Project no.:** 19280
Project title: Canadian Spallation Ultracold Neutron Source	

Need for the infrastructure

1.2 UCN Production

A new generation of UCN sources is being developed at many institutes in the world, and these developments make neutron physics an exciting and vibrant field. In the previous generation (the turbine source at Institut Laue-Langevin, ILL, Grenoble, France) the UCN density was limited by Louisville's theorem. The new UCN sources use phonons for neutron cooling, and are free from the phase space limitation of the neutrons themselves.

UCN are created in superthermal sources by transporting CN into a region of material where phonons can be created. Important parameters for a source of this type are:

* CN flux

* lifetime of UCN in the material

* production rate of UCN from CN

For higher UCN production, a higher CN flux is preferable. However, with higher CN flux comes a higher heat load, which is dominated by gamma's from neutron capture in the surrounding material. For a 4He production volume, the UCN storage lifetime is limited by phonon up-scattering, which strongly depends on temperature, and the lifetime would be severely affected if the heat transport out of the source material couldn't be dealt with. Fortunately, the superfluid 4He has essentially infinite thermal conductivity, and heat can be removed very effectively. The UCN production rate is given mainly by CN's producing single phonons in the 4He. Multiphoton excitations also contribute, making effective use of higher-energy CN.

After production, UCN are extracted to a UCN guide and a storage bottle for experiments. Extraction efficiency from the source material to the UCN guide and transport efficiency to the storage bottle are important parameters to obtain higher UCN density for experiments.

1.3 The Prototype CSUNS Source at RCNP, Osaka

The Canadian source will be based on the source of Y. Masuda, which is currently installed at the Research Center for Nuclear Physics (RCNP), Osaka University, in Osaka, Japan. The source uses a Pb spallation target and the UCN production material is superfluid 4He. The source has been used to characterize UCN production from superfluid 4He [23]. A picture of the source, as it exists in Osaka, is shown in Fig. 5 (in the attached pages).

Need for the infrastructure

The UCN production volume is a 10 L vessel containing superfluid helium, located within a 20 K heavy water vessel, in turn located within a 300 K heavy water vessel. The beam is operated at 390 MeV and at 1 uA.

In an experiment conducted at RCNP in 2007, UCN were extracted from the 4He to a vertical UCN guide of 1.2 m height and transported to an experimental port through a horizontal UCN guide of 3 m length. At the experimental port, the UCN density was 10 UCN/cc at E_C=90 neV. E_C is the maximum UCN energy, determined by the properties of the guide material used. The UCN storage lifetime was 30 s. The results are consistent with a model of neutron transport and phonon production in the source. For the model, an important consideration is the inclusion of multi-phonon excitations in the superfluid 4He. These excitations allow higher energy neutrons to be downscattered thereby increasing the UCN production rate [24]. The result shows that UCN losses upon extraction from the superfluid helium and transport through the UCN guides are small.

1.4 Canadian Spallation Ultracold Neutron Source Parameters

At TRIUMF, the 500 MeV proton beam will be used at 40 uA current. The production scales approximately proportional to beam power, giving a factor 51 projected increase in UCN density over the prototype UCN source at RCNP, Osaka. Other gains will be had from a reconfiguration of the source. The configuration of the superfluid 4He (He-II) in the source will be altered from the present vertical arrangement at RCNP to the horizontal arrangement displayed in Fig. 4. In this way, the CN flux in the He-II will be doubled simply by decreasing the average distance of He-II from the spallation target.

A UCN density in the 4He of 55,000-110,000 UCN/cc is expected internal to the superfluid volume, where a conservative storage lifetime of 150 s was assumed (limited by wall losses, and to a lesser extent phonon upscattering). After the production, UCN are extracted horizontally into a UCN guide, and transported to experiments. This horizontal extraction gives another relative gain over the RCNP prototype source. Taking this into account, the UCN density at the experimental port of the CSUNS source would be 10,000 UCN/cc at E_C=90 neV. The horizontal guide quality will be improved over E_C=90 neV, however we keep the estimate of 10,000 UCN/cc as a conservative estimate.

The UCN source will initially use 20 K heavy water (D2O) as the cold neutron moderator, which we intend to eventually upgrade to liquid deuterium (LD2). D2O is preferred initially for its comparability to the existing Japanese source, the simpler safey issues compared to LD2, and due to cost considerations. The disadvantage of D2O at 20 K, is that the CN temperature will be 80 K, while for LD2 it would be truly 20 K. D20 is therefore not as well-matched to the phonon dispersion curve in superfluid 4He. The

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Need for the infrastructure

better matching of LD2 would increase the relevant CN flux, resulting in an eventual UCN density of 50,000 UCN/cc. The LD2 moderator would be pursued as a future upgrade to the TRIUMF UCN source.

The comparison of some of the parameters of this source to the rest of the world's UCN projects is summarized in Table 1 (in the attached pages at the end of the "Quality of the Research" section). For CSUNS, the numbers for both D2O and D2 moderators are included.

The beam power we can accept is limited by gamma heating from neutron captures in the surrounding material. According to a computer simulation, the power deposited by gamma heating in the superfluid is 8 W for our operating proton beam power of 20 kW. Fortunately, this heat can be quickly removed by making use of the excellent thermal properties of superfluid helium to transfer the heat rapidly to a 3He cryostat and through a heat exchanger. As a result, the heat is transferred to 3He gas via 3He vaporization, and then removed by 3He pumping. The latent heat of 3He is 35 J/mol. The cooling power of the 3He pumping is represented as the product of the latent heat of vaporization, the vapor pressure, and the pumping rate, divided by RT, where R is the ideal gas constant and T temperature. The saturated vapor pressure of 3He is 3 Torr at 0.8 K. Therefore a pumping speed of 10,000 cubic meters per hour applied to the 3He at 3 Torr removes 17 W of heat. To further reduce the heat load, a CN filter will be placed between the spallation target and the superfluid 4He volume, thereby reducing the number of hotter neutrons entering that volume.

Therefore, we estimate that the heat loads expected for instantaneous 20 kW beam power are well in hand for TRIUMF. We note that taking the technology to significantly higher proton beam currents, such as those available at PSI, SNS, or JPARC (the Japan Proton Accelerator Research Complex), would not be possible at this time. It is only the demonstration of this new technology in Canada that would lead to future, even higher density UCN sources worldwide. This is an important reason for the creation of CSUNS in its own right.

In order to operate at TRIUMF, the source will require additional infrastructure particular to the implementation in Canada, and primarily particular to the creation of a dedicated user facility at significantly increased beam power over the RCNP prototype UCN source. It is mainly this infrastructure which would be supported by CFI funds. The details of the UCN source infrastructure is described in more detail in the "budget justification" section.

2 The research cannot be supported using existing infrastructure

As stated in the previous section, and as will be described in the next section, no

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Need for the infrastructure

similar infrastructure exists in Canada or anywhere else in the world. Future sources are planned outside Canada. The Canadian project will even surpass the future sources in its capabilities.

3 Similar Infrastructure Planned Elsewhere

No similar infrastructure is available within Canada, nor is any similar infrastructure planned for Canada. This effort is totally unique with a window of opportunity that we must capitalize on. Even outside Canada, no other similar infrastructure is available at this time; similar infrastructure is planned in the future in other countries. In the next section, we summarize these efforts and explain how the Canadian effort would surpass them.

3.1 Summary of Other New Generation Sources

A list of new generation sources was presented in Table 1 of section "Quality of the Research", and we remind the reader of the projects in that table (acronyms explained there as well):

* CSUNS (TRIUMF), spallation 4He, 10,000-50,000 UCN/cc.

* ILL, CN beam 4He, 1,000 UCN/cc.

* SNS ORNL, CN beam 4He, 150 UCN/cc.

* Munich FRM-II, reactor SD2, 10,000 UCN/cc.

* NCSU Pulstar, reactor SD2, 1,000 UCN/cc.

* PSI, spallation SD2, 1,000 UCN/cc.

* LANL, spallation SD2, 145 UCN/cc.

Of these, the LANL source is the only one currently in operation, on a testing basis.

This section is continued in the attached pages.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Management Plans

Criterion Standard:

The management plans provide for the optimal implementation, operation, and functionality of the infrastructure. The infrastructure requested will be managed effectively and efficiently, in keeping with the size and degree of complexity of the project.

Each of following aspects must be addressed:

1. Describe the management structure to oversee the implementation, operation, functionality and sustainability of the infrastructure.
2. Explain how the institution will address issues of access and utilization, taking into account scientific and user priorities.
3. If applicable, describe any changes or modifications to existing plans as a result of the infrastructure being requested and the integration or linkage with existing infrastructure.

1 Management Structure for Implementation, Operation, Functionality and Sustainability

The management structure for CSUNS will follow the usual structure of most medium to large scale subatomic physics experiments. The collaboration will be led by a spokesperson who is ultimately responsible for management decisions. J. Martin will serve as spokesperson through the completion of the construction and commissioning phases of the UCN source and through the completion of the first experiment on neutron decay.

Assisting the spokesperson will be an executive council comprised of members of the CSUNS collaboration. Equity on the council between Canadian and Japanese collaborators will be mandated. Once funded, we envision expanding the collaboration significantly both within Canada, and internationally, and such rules would be expanded accordingly.

The spokesperson and executive council will be responsible for the successful operation and utilitization of the UCN source. Within the executive council, there will be members local to the TRIUMF facility, who will be responsible for the construction and day to day operations of the source.

W.D. Ramsay (a senior research associate in the Winnipeg/Manitoba group) is the "liaison to TRIUMF". This position would continue throughout the construction and commissioning phase of CSUNS. The liaison is responsible for communications between the CSUNS collaboration, TRIUMF management, and the relevant engineering and technical groups at TRIUMF that are involved.

Once construction of the facility begins, C. Davis (TRIUMF) will serve as the technical coordinator of CSUNS. The technical coordinator will be responsible, initially, for overseeing the installation and construction of the UCN source. This will involve supervision of technicians and contractors who will perform the installation. Once the commissioning phase of the experiment begins, the technical coordinator would be responsible for overseeing day-to-day operations and maintenance. The technical coordinator is also responsible for safety and liaising with the TRIUMF safety office.

A local base of individuals at TRIUMF would be responsible for managing the day-to-day operations of the UCN source. This human resource would be maintained at all times. For example, the liasion to TRIUMF and technical coordinator positions would be comprised of TRIUMF scientific staff supplemented by research associates within either the Canadian or Japanese groups (similar to the way W.D. Ramsay's position is supported by NSERC subatomic physics project grants).

Technical developments and design studies are being conducted in Japan, supervised by Prof. Y. Masuda. During the installation and commissioning phase, it will be critical for Prof. Masuda to be located at TRIUMF. His position at TRIUMF would be supported by KEK and TRIUMF jointly, through a visiting scientist agreement. Several other scientists from Japan would temporarily relocate to Canada in a similar fashion, along with their trainees (graduate students and postdoctoral fellows).

For tasks requiring the expertise of physicists, the installation and commissioning process will be assisted by professors, postdocs, and students from the CSUNS collaborating institutions. Overall coordination of such efforts will be overseen by the technical coordinator.

For infrastructure acquisition and development, a Gantt chart has been created showing a schedule for each major infrastructure item requested in the grant. The chart will be presented and discussed further in the financial section. Detailed physicist, engineer, and technician personnel estimates for the project have also been conducted in communication with TRIUMF and will be discussed in the budget justification section of the finance module. Technical human resource needs will be provided by a combination of CFI funds and by an in-kind contribution from TRIUMF.

2 Access, Utilization, and Scientific and User Priorities

The experiments that will be conducted at CSUNS will follow the usual approval process at TRIUMF. This involves presentation of the proposed experiment to the TRIUMF Experimental Evaluation Committee (EEC) for subatomic physics. The EEC is comprised of international experts in subatomic physics. The committee makes a decision on the scientific priority of the experiment relative to other possible experiments. This existing structure, that has already been created by the laboratory, will be a very important way to establish the scientific credibility of the CSUNS program. The CSUNS project itself has already received approval from a special TRIUMF EEC meeting, which focused on projects requesting approval for the next TRIUMF NRC five-year funding period (2010-2015).

Once the scientific approval process is complete, scheduling of the experiments will be decided by the CSUNS collaboration in communication with the TRIUMF laboratory director, N. Lockyer.

3 Integration or Linkage with Existing Infrastructure

We have discussed the issue of integration into the existing facility at TRIUMF in great detail with the TRIUMF director, management, and with various users already conducting research at the facility (initiated through presentations at TRIUMF Users Group meetings and working group sessions). Based on these and on subsequent discussions, the concept for the implementation of the CSUNS project at TRIUMF was decided. This plan has been agreed upon with TRIUMF director.

The UCN source makes use of the proton beam available from the existing TRIUMF cyclotron. The cyclotron is an H- cyclotron which has been in operation since 1974. It has provided high-intensity continuous proton beams to users for fundamental and applied research since then.

Independent beams are normally provided on one of two beam ports and proceed down beamline 1A (BL1A) and 2 (BL2). The UCN source would make use of Bl1A, which proceeds east of the cyclotron into an area known as Meson Hall (see the floorplan attached to this document). That beamline is currently used by one subatomic physics experiment (called Pi-e-nu), and by condensed matter and materials scientists conducting muon spin relaxation (muSR) experiments. Pi-e-nu will be completed in 2011. After this time the installation of fabricated sections of CSUNS would proceed in the floorspace vacated by Pi-e-nu.

As will be discussed in the financial section, the Meson Hall location offers CSUNS a variety of other pre-existing infrastructure that will be utilized in various ways. The most important of these is a beam dump located at the far southeast corner of the Hall. For sensitive, low-background subatomic physics experiments, it is very important to pulse the proton beam on the spallation target so that the experimental measurements can be conducted during the period when the beam is "off". At TRIUMF, this will be achieved instead by diverting the proton beam onto the CSUNS spallation target periodically using fast "kicker" magnets. The rest of the time, beam would proceed to the beam dump in Meson Hall (as it normally does now).

A side benefit of this plan is that the UCN source would only disturb the other users

Management Plans

in Meson Hall (muSR) a projected 7% of the time. Exactly how this is achieved will be discussed in more detail in the budget justification section of the finance module. We therefore envision that CSUNS will be a well-integrated project at the laboratory.

Applicant institution: The University of Winnipeg	**Project no.:** 19280
Project title: Canadian Spallation Ultracold Neutron Source	

Operation and Maintenance Plans

Criterion Standard:

The plans for the optimal operation and maintenance of the proposed infrastructure for the first five years of operation are appropriate and realistic. They will allow for its sustainable usage as well as provide for future upgrade requirements.

Each of following aspects must be addressed:

1. Describe the significant requirements to efficiently operate and maintain the infrastructure (e.g., personnel, utilities, supplies, upgrades, etc.).
2. Outline the sources of support for operation and maintenance costs and describe the contingency plans should any of this support be unavailable.

1 Operations and maintenance plans

Operation of the UCN source will be the responsibility of the CSUNS collaboration. Maintenance of CSUNS will have shared responsibility with the TRIUMF laboratory. Both aspects represent the typical relationship of a research group (in this case, CSUNS) with the laboratory where the experiment is performed (TRIUMF). This relationship will now be discussed in more detail.

1.1 Operations and Maintenance Periods

The 500 MeV proton beam from the TRIUMF cyclotron is generally operated 24 hours a day, seven days a week, in eight-month periods. The remaining four-month period is used as a maintenance period and for major renovations and installations. It is planned, for example, that CSUNS would be installed during a somewhat expanded maintenance period, creating as little downtime as possible for cyclotron users.

1.2 Operations when running experiments

Operation of the UCN source during the eight-month running period will also be conducted on a 24 hour a day basis, dependent on the run schedule of the particular experiment being conducted using CSUNS. This is in fact expected of all experiments conducted at the laboratory, to maximize the efficient use of the available proton beam. During such times, a rotating three-person shift crew will be responsible for running the UCN source and experiment. This is typically what is done, for example, at the LANL UCN source, and at other nuclear physics experiments, dependent on the complexity of the experiment. The crew will be comprised of members of the CSUNS collaboration, including professors, research scientists, postdocs, graduate students, and undergraduate students from all countries involved. In addition to experiment and source operations, the shift crew for the experiment is typically in continual contact with the cyclotron accelerator operators, who are responsible for delivering high-quality, intense proton beam to the experiment. The typical shift load for a collaborator on similar experiments is one month of shifts per year. Our collaboration size, supplemented by our students and postdocs, is consistent with this expectation.

Operations, when running, will be overseen by a run coordinator. This will be a rotating two-week position staffed by members of the collaboration at the PhD level or higher (postdoc and above). The run coordinator will report to the liaison to TRIUMF, and will be responsible for communications with accelerator division at TRIUMF.

During this 24-hour a day running mode, a host of experts will be available to the shift crew on an on-call basis. These are typically individuals who constructed the particular physics experiment that is running at the time, and scientific staff and technicians who are responsible for the CSUNS infrastructure.

Beamline operations and maintenance will be the responsibility of the TRIUMF Accelerator Division and their technicians. This division of beamline versus experiment (in this case including the UCN source) is the usual arrangement at most laboratories. Indeed it is the Accelerator Division and accelerator operators that will control all beamline parameters when in operation.

1.3 Maintenance Personnel

The same expert users, supplemented by technicians from the laboratory, will be responsible for maintenance of their experimental equipment. TRIUMF scientific staff will be responsible for oversight in the maintenance of CSUNS equipment once installed at TRIUMF. However, two technicians will be necessary to maintain the infrastructure. One technician would be responsible solely for all cryogenics infrastructure (ultimately keeping the superfluid 4He at 0.8 K). The other would be responsible for all other tasks, generally maintenance of vacuum systems, of the spallation target, and for overseeing crane operations should large equipment or shielding blocks need to be moved. The requirement of two technicians is consistent with technical staff present at the Los Alamos source. We therefore envision asking for two technicians, stationed at TRIUMF, as a part of a future CFI Infrastructure Operating Fund (IOF) request.

1.4 Utilities and Supplies

The main utility required is electricity to power equipment such as vacuum pumps, refrigerators and coolant circulating systems, monitoring equipment, and computers. Compressed air is required to operate certain vacuum valves. Such utilities would be provided by the TRIUMF laboratory in the usual fashion.

The dominant expense in supplies for the UCN source is the supply of liquid helium for cooling. A system that does not reclaim the helium is wasteful and not sustainable. The liquid helium consumption of the UCN source is 200 L/day during operation, which is the size of a typical dewar.

Fortunately, a new central helium liquifier system will be present at TRIUMF by 2011, and in discussions with TRIUMF we have negotiated to make use of this system. All helium vapour from boil-off at CSUNS will be recovered to a compressor system and then to a pressurized storage container that will feed the liquifier. Liquid helium thereby produced by the liquifier will be stored in a large dewar, which will be tapped periodically to fill a local dewar at CSUNS. This is a highly sustainable practise done at most universities and laboratories requiring large amounts liquid helium.

Nonetheless, losses from such systems occur, and we envision topping up the helium supply periodically. This would be another aspect of a future CFI IOF request.

1.5 Radiation Safety

Radiation would be produced in the UCN source, and in fact a great deal of the engineering of the spallation target and surrounding infrastructure itself goes into safely dealing with this issue. Fortunately, the issues encountered are not outside the normal scope of the TRIUMF laboratory. The laboratory currently operates a spallation target for the production of radioactive beams. Maintenance of the target would therefore be conducted according to TRIUMF policies and procedures by highly trained TRIUMF staff. This sort of maintenance would be overseen directly by the TRIUMF Environmental Health and Safety group.

1.6 Future Upgrades

Eventually, we intend to request an upgrade through CFI for a cold liquid deuterium (LD2) moderator at a temperature of 20 K. Having such a moderator would increase our UCN density by a projected factor of five. This will be pursued at a later time because this version of the source involves a significant increase in the scope of the project in terms of safety, complexity, and materials costs.

2 Sources of Support for Operations and Maintenance Costs

As discussed in the sections above, the main source for most operations and maintenance

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Operation and Maintenance Plans

costs, particularly those related with radiation safety and the proton beamline, is TRIUMF. This is only the most natural of arrangements, given the expertise of the TRIUMF laboratory, and the typical division that occurs between beamline and experiment (in this case including the UCN source).

Where we envision requesting support from CFI IOF is primarily for the support of technicians and for periodic liquid helium top-ups accounting for our impact on the TRIUMF central helium supply. These requirements are normally outside the domain of the laboratory. This assistance would contribute to the long-term viability of the UCN source and would be unique to CSUNS. We envision IOF would pay for half these operations and maintenance costs and the contribution would be matched by TRIUMF.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Training of Highly Qualified Personnel (HQP) Through Research

Criterion Standard:

The infrastructure requested will create or enrich a stimulating and innovative training environment that attracts high quality trainees and imparts new high-level skills to HQP for research and other careers.

Each of following aspects must be addressed:

1. Describe the benefits of the proposed infrastructure for research training and career development.
2. Outline the extent to which the proposed infrastructure will be accessed directly by research trainees.
3. Describe the impact of the proposed infrastructure on future training of HQP as well as the impact that not having access to the proposed infrastructure would have on training. Include an estimate of the number and type of HQP (e.g., undergraduate and graduate students, postdoctoral fellows, technicians, technologists, other trainees/students) to be trained.

1 Benefits of CSUNS for research training and career development

Performing research on fundamental 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 complete 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 the project leader 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 incredibly diverse range of potential job opportunities, in such a large variety of technical fields, represents the range of impact possible from one who has been trained as an experimental nuclear physicist.

University of Winnipeg students trained in J. 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 (awarded for high academic standing and citizenship, and considered to be the top undergraduate award at the University of

Winnipeg), and an NSERC PGS-D awardee. Three students have been awarded NSERC USRA positions. This is a sampling of students in the past four years since Prof. Martin took up his position at the university.

1.1 Acsion Industries and Radiation Technology

As will be described in the "Collaboration and Partnerships" section and in the "Budget Justification" section of the Financial Module, the University of Winnipeg has partnered with a local Manitoba business, Acsion Industries, to develop a computer model of neutron transport in the UCN source. A large part of the agreement relates to the training of HQP, in this case graduate students and postdoctoral scholars from the University of Winnipeg and the University of Manitoba.

The simulation thereby created will be based on the Monte-Carlo N-Particle (MCNP) simulation. Training in writing such custom computer codes will be an integral part of the education that the students would receive. The training will open the students up to the other possibilities available at Acsion, for which very similar techniques are used to protect the public (radiation safety and health protection consulting services), protect patients (medical products), and protect farmers and consumers (crop enhancements, food treatment, pharmaceuticals, waste products). Acsion has generated similar computer codes to model nuclear reactors. The training that students would receive could lead their careers in that direction, possibly leading to the design of new reactors for power generation.

Acsion Industries also operates its own electron beam treatment centre to commercialize specific radiation-related technologies and for training safety professionals. Access to CSUNS and TRIUMF could assist in this endeavor.

Acsion supplies consulting services in all aspects of industrial and radiation safety to utilities, engineering companies and research institutions. Our HQP would thus be well-suited for jobs in such companies.

1.2 Aboriginal Education Efforts

A common goal of the University of Winnipeg and the TRIUMF laboratory is to educate aboriginal students in basic science.

At the University of Winnipeg, this is a very important initiative due to the university's geographical location in downtown Winnipeg, a region of the city with a large aboriginal population. At TRIUMF, a scholarship has very recently been created for aboriginal students to undertake science and engineering projects as a part of

Training of Highly Qualified Personnel (HQP) Through Research

their education.

In 2008, the two efforts came together to support the summer research of an NSERC USRA supported aboriginal student working in J. Martin's laboratory at the University of Winnipeg. The student participated in the calibration of detectors for the Q-weak experiment at Jefferson Lab. These detectors were constructed in Winnipeg, and then were taken to TRIUMF by the student to complete tests in an electron beam available there. The student's travel was supported by TRIUMF through the new scholarship.

2 Direct Access of Research Trainees to CSUNS Infrastructure

As mentioned in the section "Operations and Maintence Plans", undergraduate students, graduate students, and postdoctoral fellows would be responsible for the operation of experiments and of the UCN source. Serving data-taking shifts is one aspect of every student's experience in experimental subatomic physics.

Students and postdocs would also be responsible for a large fraction of the intellectual effort required to design the UCN source. This would be supported by the training received through Acsion Industries.

In general, students and postdocs on such projects are involved in all aspects of the projects to varying degrees, and take on responsibility for one or more smaller hardware projects related to either the particular experiment being conducted or the UCN source. Additionally, technicians would be trained using the infrastructure. Two technicians are required to maintain the UCN source.

3 Impact on Training 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.).

3.1 Canadian HQP

We estimate that four graduate students would complete MSc and PhD studies through to the commissioning of the UCN source alone. Typically four graduate students per experiment would complete MSc and PhD studies on the experiments that would eventually be conducted at CSUNS. Three postdoctoral fellows supported by Canadian institutions would be supported at any given time, and would typically be replaced in three year increments throughout the ten to twenty year experimental program at CSUNS.

3.2 International HQP in Canada

Graduate students from Japan, the U.S. and elsewhere would also be present in Canada to work at CSUNS, supported by scientists from their respective countries. We estimate that this would double the complement of graduate students and postdoctoral fellows trained at CSUNS. A unique aspect of this project would be the international environment in which our Canadian HQP would interact with students and scientists from abroad, attracted to Canada by the excellent science promoted here.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Collaborations and Partnerships

Criterion Standard:

The project will establish or enhance major collaborations and partnerships. The infrastructure requested will further strengthen multidisciplinary approaches, collaborations among researchers and users of research results, as well as partnerships with different institutions and sectors, where appropriate.

Each of following aspects must be addressed:

1. Describe the nature of the major collaborations that already exist, and that are planned, both within and external to the institution (beyond those between the principal users, as addressed in the "Researchers (Use of Infrastructure)" section in terms of:
   a) ensuring that the proposed research or technology development can be pursued successfully;
   b) promoting synergies among research disciplines and sectors (public, private, NFP).
2. Describe the nature of the major partnerships that already exist, and that are planned, with users of the research results, including the extent of the engagement of these partners.
3. Outline the steps that have been taken, or that will be taken, to create or strengthen collaborations, partnerships, and/or networks.
4. Explain why the proposed infrastructure is important to these collaborations or partnerships.

1 Collaborations

The University of Winnipeg is leading an international group of scientists in this world-class project in basic research. Thus far groups at Canadian universities, at TRIUMF, at KEK, at Japanese universities, and at institutions in the U.S. have joined the project. The division of "principal users" vs. "other users" is artificial in the case of this project. All other users have in fact agreed to sign this proposal, and have signed the proposal as previously presented to international review committees of the program (mentioned in the section "Quality of the Research").

1.a Ensuring Successful Research and Technology Development

J.W. Martin (project leader) has been responsible for this success in attracting such a distinguished list of collaborators. All of them are experts in the field of neutron physics, and are well-regarded and well-known for their achievements. The CSUNS project will bring together these excellent individuals, and bring them to Canada to conduct research there. Such an impressive collaboration ensures the success of the technological development of the UCN source, and the successful completion of the cutting-edge physics experiments that will be conducted there.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Collaborations and Partnerships

The collaborators have divided themselves into three major experimental collaborations: neutron lifetime experiment, gravity levels experiment, and the n-EDM experiment. The Canadian users would initially work on the neutron lifetime experiment.

We now summarize the qualifications of our "other users", and their experimental interests in using the UCN source in Canada.

1.a.1 Japanese collaborators

Most of the Japanese collaborators have been involved in the development of the existing Japanese UCN source. These collaborators view the n-EDM experiment as their top priority once CSUNS is commissioned.

A large group spearheaded by The University of Tokyo (S. Komamiya and collaborators) has joined this effort more recently, with the goal of eventually completing a neutron gravity-levels measurement at TRIUMF. This is a very well-known group of particle physicists. S. Komamiya is the leader of the Japanese effort at LHC, for example. The group is currently developing UCN detectors with micron-scale spatial resolution to directly observe the height distribution of neutrons confined above the mirror in the experiment. This new technology, combined with the high fluxes of UCN available at TRIUMF, would enable a new precision test of gravity. The design of the experiment and of the main detector are underway in Japan.

We also note the involvement of H. Shimizu, a materials scientist from KEK. His primary interest is in use of very cold neutrons (VCN) also produced by the source. Neutrons of these energies can be used for condensed matter studies at relatively long wavelengths compared to traditional small-angle neutron scattering.

1.a.2 U.S. collaborators

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.

R. Golub has been one of the main proponents of the field of UCN physics over the past several decades, and in the development of superthermal sources of UCN. He is coauthor of the seminal book "Ultra-cold Neutrons". He has already travelled to Japan to perform research using the UCN source there, and will provide expert input in the development of Masuda's spallation-driven UCN source at TRIUMF. He has also expressed a strong belief that this will result in the world's highest density UCN source. He 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.

Applicant institution: The University of Winnipeg		**Project no.:** 19280
Project title: Canadian Spallation Ultracold Neutron Source		

Collaborations and Partnerships

E. Korobkina is an expert on UCN production and storage experiments. She has designed a UCN ISR apparatus, and collaborates on the SNS EDM project, and the NCSU Pulstar reactor UCN source project. L. Clarke, a collaborator from the same group at NCSU, has also joined CSUNS in the hopes of eventually using UCN for condensed matter and surface nanoscience applications.

J.D. Bowman is a recipient of the prestigious Bonner prize of the American Physical Society. He is the main proponent of the magneto-gravitational UCN lifetime experiment.

B.W. Filippone, T.M. Ito, and B. Plaster, have most recently brought about the successful completion of the first round of physics measurements with the UCNA apparatus at LANL. They are also all collaborators on the SNS n-EDM project, and are responsible for the inner detector system and the magnetic field system. They are also involved in preparatory work towards the neutron lifetime experiment.

1.b Promoting Synergies

The CSUNS project by its very nature as a project in neutron physics is inherently multidisciplinary, and therefore promotes synergies among research disciplines. Through precision measurements of low-energy neutron observables, the experiments that will be done at CSUNS will probe fundamental particle physics questions. At the same time, the technology of producing UCN relies on both nuclear physics and condensed matter physics effects. The neutrons themselves, in possible future experiments, would also be used as to probe other condensed matter effects for materials science applications (the aim of users Shimizu, Korobkina, and Clarke) leading to potentially even more synergies between these different research discplines.

The collaboration of Canadian physicists at universities and at TRIUMF with physicists at Acsion Industries (a company based in Pinawa, Manitoba) is likewise expected to be a very profitable one, and promotes a synergy between the public and private sectors in Canada. The benefits in terms of expanding the core capabilities of Acsion to computer simulations of the UCN source, and the subsequent training of HQP in Winnipeg, will be immense.

2 Major Partnerships

The partnership of Acsion Industries with the rest of the collaboration has been formalized in a memorandum of understanding (MOU) between the University of Winnipeg and Acsion. Acsion will create novel computer software to model the inner workings of the UCN source, and will provide access and training on the software thereby developed.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Collaborations and Partnerships

They have copious experience in this type of simulation work, having developed and used similar software to design nuclear reactors, where the neutron transport issues are very similar in nature. University of Winnipeg HQP trained in such a fashion will assist in performing a detailed optimization of the moderators in the UCN source to maximize the output UCN density. Acsion will retain the software developed as intellectual property. The intention of the company is to use the project to build their own expertise in the area of neutron transport, and to potentially market the software and their expertise to other interested parties, for example, those designing nuclear reactors for power generation. The budget in the Acsion-Winnipeg MOU will be discussed in the Financial Module.

TRIUMF is Canada's National Laboratory for Particle and Nuclear Physics and itself is a major partnership: it is owned and operated by a consortium of universities under an operating grant from the National Research Council Canada (NRC). Currently, Simon Fraser University is a member institute in the consortium, and U. Manitoba is an associate member.

This section is continued on the attached pages.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Benefits to Canada

Criterion Standard:

The proposed activities have the potential to lead to:

- significant improvements to society, quality of life, health, and the environment, including the development of new practices and public policies; and/or
- improved economic activities through development of new products, services and/or technologies, greater resource efficiency and productivity, and job creation in strong or emerging areas of the Canadian economy.

Each of following aspects must be addressed:

1. Describe the expected benefits to Canada, including why they are significant, how they will be realized, and the timeframe over which they are expected to be realized.
2. Describe the institution's plans to transfer the research results to potential users. Where appropriate, these should include plans for knowledge mobilization or transfer of technology and the commercialization of products, services and processes.
3. Demonstrate that the team has the skills and experience, or has identified the relevant partners, to ensure the successful transfer of the research results.

1 Expected Benefits to Canada

The CSUNS project addresses the core principles of Canada's Science and Technology (S&T) strategy which is designed to make Canada a world leader for current and future generations. 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 Canada, Japan, and the U.S. clearly will be enhanced by the project, and significant funding has been committed to the CSUNS project by the Japanese part of the collaboration. 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.

Benefits to Canada

This is particularly true of Japanese and U.S. scientists.

* Many research opportunities for students would be created by the project. The project will train four graduate students through the commissioning of the UCN source, and four students per experiment thereafter. Typically three postdoctoral scholars would be working on projects at the UCN source at any give time. The development of a skilled workforce through basic research is a primary goal of this proposal.

* 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 through recruitment efforts at the University of Winnipeg.

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 magnetic resonance imaging (MRI), because exactly this technology is used in the neutron electric dipole moment experiment.

* The UCN source can potentially be used as a tool to study advanced materials, and hence to impact the fields of materials science and surface nanoscience. One example is a possible device based on UCN inelastic scattering reflectometry (ISR). The surface nanoscience experiments that could be conducted with such a device relate to the characterization of large hydrogenous molecules for "smart surfaces", where examples in medicinal drug delivery exist. Another example results in the use of very cold neutrons (VCN, also produced by the UCN source) to study materials in a unique domain compared to small-angle neutron scattering. The would potentially result in a large number of users from across the world using CSUNS to study advanced materials.

Entrepreneurial Advantage

* The UCN project has attracted the interest of a business in Pinawa, MB called 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. Acsion would also supply in-kind funding to the project. The company is involved in advanced manufacturing, based on their application of radiation technologies to manufacturing, and is involved in radiation safety and health physics.

Benefits to Canada

* 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 timeframe for the infrastructure development would be over the course of the next four years. After that time, experiments would be conducted and we have outlined a ten to twenty year program of experiments that would be conducted (see section "Quality of the Research or Technology Development" for a more complete description of the experiments).

The immediate goal of creation of the highest density ultracold neutrons ever achieved in the world would therefore be completed in four to five years. The completion of the first flagship experiment, the neutron lifetime experiment, would be expected two years after that time, and would result in new knowledge on this fundamental parameter of astrophysics and impacting the standard model of particle physics. Thereafter, the neutron gravity levels experiment would be conducted, followed by a ramp-up of efforts on the n-EDM experiment. In twenty years we envision that those experiments would be completed and again new knowledge on physics beyond the standard model would be acquired.

2 Transfer of Research Results

Research results will be disseminated through scholarly journals and to the public through the media and the internet. Considerable excitement over the project is expected, as is warranted for discovery science projects of this sort. (We cite the recent press relating to the turn-on of the Large Hadron Collider LHC at CERN in Geneva, Switzerland.)

The work done by Acsion Industries has the potential for commercialization. The software that they will develop will be granted through a license to the collaboration to use through an in-kind agreement. Acsion however maintains intellectual property rights to the software that is developed. They intend to market the software to other interested parties (potentially users interested in designing nuclear reactors for power generation, or users interested in designing advanced neutron sources for condensed matter and materials science).

3 Ensuring the successful transfer of the research results

The dissemination of results through publications in the relevant journals is clearly the main method that all our collaborators are familiar with.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Benefits to Canada

Media relations would be conducted through the relevant universities and through TRIUMF, through the TRIUMF Head of Strategic Communications, Timothy Meyer.

Acsion Industries has been successful in attracting a variety of clients in related technologies in the past. They are therefore an excellent partner for us to have to assist in technology transfer. The Canadian universities also have technology transfer offices to assist in this regard. Additionally, Advanced Applied Physics Solutions Inc. (AAPS), a not-for-profit subsidiary of TRIUMF supported by the Government of Canada's Networks of Centres of Excellence Program, has been established to assist in the commercialization of research results at TRIUMF and we envision making use of this facility as well.

Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Suggested Reviewers *

The CFI reserves the right to make its own selection of reviewers.

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

Suggested Reviewers *

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Applicant institution: The University of Winnipeg **Project no.:** 19280

Project title: Canadian Spallation Ultracold Neutron Source

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