Discussion on a Virtual Institute for Neutron Scattering:

A concept paper prepared for
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and
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by
Canadian Nuclear Laboratories

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1.0 Executive Summary

Neutron beams are versatile infrastructure for Canadian research on materials ranging from fundamental exploration to failure analysis of critical industrial parts, such as engines, pipelines, railroad tracks, and turbines. A renewal of this infrastructure could lead to economic and public good impacts in several focus areas of Canada's S&T strategy, including Advanced Manufacturing, Natural Resources and Energy, Health and Life Sciences, and Agriculture.

Canada's only major neutron source, the NRU reactor, will close in March 2018, and without infrastructure renewal, Canada will lose a major scientific user facility: each year, over 200 scientists, engineers, and students from universities, government labs, and industry participate in research depending on access to the six beamlines at NRU.[1] A new neutron source in Canada – if one is built – will not be fully operational for a decade or more; this time period is referred to as the 'neutron gap'. The expectation of a lengthy neutron gap and the uncertainty about a new neutron source are serious threats to Canada's materials research capabilities.

This discussion paper explores how a Virtual Institute for Neutron Scattering (VINS) could play a role in stabilizing and eventually growing the national capability for materials research by securing resources for neutron beam infrastructure. A VINS would foster this capability primarily by developing, operating and facilitating access to neutron beam instruments in Canada and at some of the best neutron sources worldwide. A VINS would also foster capability by performing research and development of equipment and techniques, providing complementary theoretical expertise and modelling facilities, supporting student training, developing applications and services to industry, and overseeing public investments.

A VINS would perform some activities at a home institution, but experimental research activities must be conducted at 'outstations' located at neutron beam labs elsewhere; for this reason the VINS is a virtual institute. Securing partnership with at least one neutron source is thus critical to a VINS.

Equally critical to a VINS is the participation of Canadian universities. The governance of the VINS should reflect a pan-Canadian approach and the strong academic interests. Positioning the VINS within the academic sector is needed to apply to the Canada Foundation for Innovation (CFI), which is the primary academic funding source for both capital projects and operations. These factors suggest that the VINS could be formed initially as a consortia or joint venture of universities.

This discussion paper provides background and preliminary analysis about a VINS for discussion by the neutron scattering community, including the science and policy context, stakeholder analysis, mission and scope, a vision for a VINS in Canada, and practical matters of governance, costs, funding sources and a possible timeframe for implementation.

[1] Over a five-year period, CNBC research participants include more than 700 individuals from over 60 departments in over 30 Canadian universities and from over 100 foreign institutions in over 20 countries.

2.0 Background

2. 1 Science and Industry Applications of Neutron Beams

2.1.1 Neutron Beams are Tools for Studying Materials [2]

Everything is made of materials. That means the Earth, houses, food, tools, cars, computers, phones, artificial hip joints, diseases and humans - everything. Advances in materials lead to positive impacts across the spectrum of human experience and society. Such advances arise from the work of scientists in many disciplines, for example:

- Physicists study superconductors to revolutionize technologies for energy conservation, faster computers and more efficient medical diagnostics
- Chemists study the crystal structures of new materials for lithium-ion batteries, hydrogen-storage, fuel cells, or coatings for medical implants
- Engineers study how manufacturing processes affect materials at the basic level of crystal structures, looking for ways to make more reliable materials cost-effectively
- Health scientists study nano structures to design carriers for therapeutic agents that can target cancer, to design better treatments for diseases such as Infant Respiratory Distress Syndrome, or understand how bio-molecules like vitamin E function in our bodies

In all of these examples, scientists use neutron beams among various other tools to study materials, such as microscopes, X-rays, laser spectrometers and many others. Each tool reveals certain properties of materials, generating knowledge that points the direction for better understanding and improvements. Rarely does a single tool provide the complete picture.

Neutrons beams are exceptionally versatile and powerful tools for materials research because of the unique ways that neutrons interact with matter. Neutrons are neutral, sub-atomic particles, which penetrate deeply into materials. However, they are gentle probes, even of the most delicate materials, because they have low energies - one million times lower than X-rays that might be used for similar studies. Neutrons are magnetic, and allow scientists easily to learn about magnetic properties of materials at the level of molecules and crystal structures. Neutrons interact directly with atomic nuclei, and distinguish between isotopes. Notably, neutrons easily distinguish between hydrogen and deuterium, allowing scientists to focus on details of the molecular or nanostructures of polymers and biological materials, which are rich in hydrogen.

Due to these properties, neutron beams will always be an indispensable tool and cannot be replaced by other techniques.

2.1.2 Looking Ahead in Science and Engineering

As scientific inquiry evolves and engineering challenges push limits, so do scientific tools. Strong growth in the interdisciplinary areas of biochemistry and biophysics has been paralleled by the adaptation of tools from physics and chemistry to understand biologically relevant questions. While hard matter

[2] The views of the scientific community can be found in the CINS Long Range Plan: CINS. Planning to 2050 for Materials Research with Neutron Beams in Canada. http://cins.ca/reports.html#2050

continues to represent a large part of materials research, there is rapid growth in research on soft matter, including polymers, nanotechnology, life sciences and biotechnology. In parallel to this growth, neutron beam facilities have been tuning their capabilities to meet these demands. Cold neutron sources and beamlines for small-angle neutron scattering allow scientists to make observations at the length scales of large molecules like DNA and proteins, while a variety of sample chambers are employed to apply biologically relevant conditions during the experiments.

For industrial and government researchers, metallurgy will continue to be an important area of inquiry as we continue to push the limits of metals to make them lighter or able to endure high temperature differences. Reliability of these metals underlies safe and economic operations of our infrastructure, including power plants, pipelines, bridges, cars, airplanes, ships, and railroads. Industries with low tolerance for failure need to know, with certainty, all the material properties in critical components. Neutrons beams are unrivalled in their ability to directly and non-destructively determine stress, texture, and other properties deep inside metallic components, and the Canadian Neutron Beam Centre (CNBC) has led the way in this area.[3] To meet future needs of industry, a turn-key solution for stress analysis can be envisioned that integrates the neutron data with other experimental techniques and computer modelling.

Neutron imaging, analogous to x-ray photographs, holds promise as a growth area for Canadian research. Applications include:

- boosting crops yield through imaging plant roots and the micro-organisms around the roots in soil, and correlating the results with phenotype-to-genotype correlation
- identifying of water ingress to prevent failures in critical components for aerospace and oil & gas industries
- quality assurance of nuclear fuels and fuel failure analysis for the nuclear power industry
- forensic examination for the radiological and nuclear community

2.2 Federal and Provincial Policy Context

Governments in Canada are interested in considering two potentially-related investments in nuclear S&T that may have neutron beam components: (1) a nuclear innovation agenda (NIA), and (2) a new source of neutrons.

The federal position on a NIA was recently summarized thus by Natural Resources Canada (NRCan):

[3] Several examples of current impacts arising from industrial projects at the CNBC are found in its recent activity report: Canadian Neutron Beam Centre. Activity Report to the Canadian Institute for Neutron Scattering for 2011, 2012, and 2013. http://cins.ca/reports.html#cnbc.

> *The government is seeking to understand the potential value to Canada of a cost-shared research and development initiative, taking into consideration benefits to Canada's innovation capacity, and potential for improved competitiveness of nuclear and non-nuclear sectors, jobs and growth*.[4]

The nuclear industry, led by the Nuclear Leadership Forum, has responded to NRCan's encouragement to consider a cost-shared NIA, and is proposing to establish a framework for shared decisions about investing in nuclear science and innovation, involving federal, provincial, industrial and academic stakeholders.[5] The NLF has proposed that the framework could be a vehicle for funding projects that require access to nuclear research infrastructure or funding capital and operations of such infrastructure, which may include a new neutron source.

The federal government has expressed openness to considering co-investment in a new neutron source.[6] The Ontario Minister of Energy has spoken publicly about need to plan now for a new research reactor to replace the NRU reactor to support the nuclear industry.[7] The Government of Saskatchewan expressed interest in 2009 in building a neutron source at the University of Saskatchewan[8] as one means of building nuclear capabilities to support industry expansion in the uranium lifecycle beyond mining.[9] The province has since made parallel investments to build nuclear capabilities by establishing the Sylvia Fedoruk Canadian Centre for Nuclear Innovation in 2011. A source of neutron beams would be a valuable asset to enable research sponsored by the Fedoruk Centre and that conducted by the recently announced Phenotyping and Imaging Research Centre to be established as result of a recent $37.M award from the Canada First Research Excellence Fund. The Phenotyping and Imaging Research Centre proposes to use neutron imaging as one of its techniques to correlate genotypes and phenotypes, enabling genetic engineering of crops that are tuned to thrive in the specific environments found around the world.

2.3 Global Supply and Demand

All the North American neutron beam facilities are heavily oversubscribed[10] and the USA continues to grapple with issues of accessibility of neutron beam facilities to American scientists[11] despite increasing

[4] "Exploring a Potential Industry-driven Nuclear Innovation Agenda", Presentation by S. Quinn of NRCan at the UNENE R&D Workshop, December 16, 2014. Former NRCan Minister Greg Rickford spoke favorably of how nuclear S&T is being applied to innovation in non-nuclear industries (Speech to Canadian Nuclear Association conference, Feb 2015).

[5] The Nuclear Leadership Forum. Enabling the Next Generation of Nuclear Science, Technology and Innovation A nuclear innovation agenda for a powerful Canada to 2040 and beyond. Draft. March 3, 2015.

[6] See for example, NRCan's Response to the Expert Review Panel on Medical Isotopes: http://www.nrcan.gc.ca/energy/uranium-nuclear/7795.

[7] Bob Chiarelli. Speech to Canadian Nuclear Association conference, Feb 2015.

[8] The Province of Saskatchewan offered in 2009 to provide 25% of both the capital and operating funds for a neutron beam facility located at the University of Saskatchewan, complementing investments at the Canadian Light Source (The Canadian Neutron Source. http://cins.ca/reports.html#isotopes1).

[9] Uranium Development Partnership. "Capturing the Full Potential of the Uranium Value Chain in Saskatchewan." 2009.

[10] For example, "[the NIST Centre for Neutron Research's] oversubscription rates by beam line are in a healthy range, averaging 2.2 over the facility, indicative of a robust and vibrant user community." (Laboratory Assessment Board. An Assessment of the National Institute of Standards and Technology Center for Neutron Research: Fiscal Year 2011. p.9. http://www.nap.edu/openbook.php?record_id=13252). The oversubscription rate is defined as the number of beam days requested by users, divided by the total number of beam days available for user access.

the supply by ramping up its new $2.2B Spallation Neutron Source (SNS, 2006) and expanding capacity at its two remaining older, NRU-vintage, facilities[12]. The shortage is in part due to closures of other US facilities at Argonne and Brookhaven labs, and most recently the user program at Los Alamos. Unless new facilities are built, the SNS could become the only major neutron beam facility in North America in the coming decades, and will be unable to meet current demand levels, even if it invests in a second target station at SNS.

Globally, most neutron beam facilities are based on aging reactors built within 20 years of the NRU reactor, and like the USA, other countries are investing or have recently invested in new or upgraded facilities, including Japan ($2.4B, 2008), Australia ($350M, 2008), Germany ($750M, 2001), UK ($280M, 2009). A consortium of European countries is now constructing a $2.5B spallation neutron facility. Materials research with neutron beams was the main reason for these investments.

2.4 Canada's Neutron Scattering Capabilities Today

Canada has built a strong international profile in materials research with neutron beams, for selected scientific domains, including applied neutron diffraction for industry, quantum materials and powder diffraction. Canada is also noted for innovation in neutron instruments, methods, and applications. Canada's neutron beam capability has four main elements:

1. One major neutron source (NRU) with an internationally competitive neutron flux.
2. A community of 250 Canadian academic, government and industrial users of neutron beams, as well as 150 foreign researchers, organized by the Canadian Institute for Neutron Scattering.
3. Six beam lines accessible by an international research community at the Canadian Neutron Beam Centre (CNBC).
4. Scientific and technical expertise at the CNBC that enables effective application of neutron methods to a wide range subject matter, and continuously advances neutron capabilities.

Some incremental capacity is available for Canadian researchers:

1. Under an arrangement to expire in 4-5 years, Canadian researchers are welcome to use up to 10% of the time of three beamlines at the Spallation Neutron Source (Oak Ridge, USA).
2. The lower-flux McMaster Nuclear Reactor (MNR) has two beamlines for commercial radiography operated by N-Ray Services Inc. for commercial applications, and a third beamline that can introduce students to neutron diffraction, and enable specimens to be aligned and evaluated prior to taking them to higher-flux sources for a full-scale experiment. A fourth beamline for small-angle neutron scattering being built by the CNBC is expected to be operable in 2019.

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[11] Henry Glyde, Robert Briber, Sunil Sinha. Committee on International Scientific Affairs of the American Physical Society. "Access to Major International X-ray and Neutron Facilities." April 30, 2009. http://www.aps.org/programs/international/resources/facilities.cfm

[12] (1) The National Institute of Standards and Technology (NIST) Centre for Neutron Research and (2) the High Flux Isotope Reactor at Oak Ridge National Laboratory.

2.4.1 Strengths and weaknesses compared to major foreign neutron beam labs

Despite the relatively low investment by Canada in the infrastructure and resulting capacity limitations, the return on investment is high compared to most foreign facilities.[13]

Strengths

- Strong international reputation supported by a competitive publications per instrument ratio[14]
- Competitive instruments for industrial applications, powder diffraction, and quantum materials
- Both the CNBC and its user community are highly collaborative with industry[15]
- More attention to teaching students and casual users, which fosters a national capability
- Being at CNL has provided complementary capabilities to handle radioactive materials and enables services for nuclear and non-nuclear industries, difficult to emulate elsewhere

Weaknesses

- Current lack of formal stakeholder involvement in funding, governance, or operations[16]
- Sub-standard staff-to-beam line ratio make 24/7 operations and user support challenging
- Operating within agencies without strong mandates to provide national user facilities
- Minimal capital investment in facilities over past 20 years[17]
- Lack of a cold source and cold neutron beamlines for polymers and bio-materials
- Small number of beamlines (6 compared to a range of 15 to 50 at foreign neutron sources) and gaps in thermal neutron capabilities (e.g. radiography)
- Fewer complementary capabilities for sample preparation, theory and modelling, and instrument development

2.5 Canadian stakeholders

The CNBC has historically operated in the international framework of a 'user-facility model,' sharing a major resource for R&D widely amongst a diverse research community. This section briefly describes the community and examines the user facility model.

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[13] The CNBC's "industrial applied research program is the best in the world" (Peer Review of the Steacie Institute for Molecular Sciences: Final Report of the Institute Review Committee", presented to the NRC Council, October 28, 2004); An international expert panel (U.S., France, Canada) stated, "CNBC is competitive with the top scattering research facilities in the world, based on quality of research and publications." (NSERC Site Review of the Canadian Neutron Beam Centre, Feb 11, 2007).

[14] Some of this reputation is also due to other factors: Canadians of stature are active in the community of USA facilities or in the Neutron Scattering Society of America. CNBC is known for some historic achievements: Bertram Brockhouse's Nobel Prize and the neutron stress-scanner replicated at other facilities in the 80s and 90s.

[15] For example, the CNBC and its user community "has the most diversity in terms of the industries that sponsor research" compared with TRIUMF, CLS. See KPMG. "A Report on the Contribution of Nuclear Science and Technology (S&T) to Innovation." Final report prepared for Natural Resources Canada. Fall 2014. p147

[16] Today, the CNBC is the only academically-oriented user facility in Canada that is not operated by the academic sector, apart from federal astronomy facilities due to provisions of the NRC Act. The CNBC was partially supported through the granting councils from 1992 to 2013 in lieu of access fees for university researchers. With a moratorium on the NSERC Major Resources Support program, the academic community is currently without a means to contribute to the funding and governance.

[17] Investment in the global market for neutron beams is discussed in the previous section. An NRCan study found the CNBC had nearly no capital investment compared to major academic-sector facilities in Canada (e.g. TRIUMF, CLS, McMaster Nuclear Reactor) over the past 20 years (see KPMG. "A Report on the Contribution of Nuclear Science and Technology (S&T) to Innovation." Final report prepared for Natural Resources Canada. Fall 2014).

2.5.1 Academic Researchers[18]

Universities benefit both from the knowledge they generate and from the training their students receive at the user facility. Canadian academics gain access to foreign facilities and international collaborations, balanced by Canada's user facility contributing to a global network of neutron beam laboratories.[19]

The CNBC user community includes researchers from over 60 departments in 30 universities, including nearly every major university and some smaller ones. A recent study found that the geographic distribution of faculty who use the CNBC matches the distribution of universities across Canada, and the number of faculty is equal to the numbers that use TRIUMF and the Canadian Light Source (CLS), whose users tend to be more regionally aligned. Further, the faculty involved in the CNBC were found above average in both scientific stature and engagement with industry.[20] Thus, materials research with neutron beams is one of the few areas of strength in academic – industrial collaborations, where Canada otherwise ranks weakly internationally.

2.5.2 Industry Clients

Industry clients tend to come from risk-sensitive heavy industries where precise knowledge of the properties of key materials is needed to ensure reliability and meet regulatory requirements: nuclear power, aerospace, automotive, oil & gas, primary metal production and other manufacturing. These industries pay to directly employ neutron beams in failure analysis, prototyping or other R&D to improve manufacturing methods or satisfy regulators. Paid projects tend to be one-offs, urgent in the short-term, high impact and proprietary. Longer-term involvement with industry typically arises when industries pool resources (e.g. through the CANDU Owners' Group, Pipeline Research Council International) and sponsor academic or government labs to solve longer term materials problems that may benefit an entire industry.

Canadian Nuclear Laboratories (CNL) has been the CNBC's largest client outside academia. The end users of the knowledge generated for many CNL projects have been the Canadian nuclear power industry or government regulatory bodies (e.g. Canadian Nuclear Safety Commission or Health Canada). In other cases, these projects have contributed to CNL's operational needs as a nuclear site. Projects over the past three years have included nuclear forensics, nuclear waste management, quality assurance and analyses of fuel produced in the Nuclear Fuel Fabrication Facility, and studies on hydrogen in CANDU pressure tubes, understanding fuel failure, reliability of welding methods, super-critical water reactors and biological effects of radiation. Over the past 15 years, CNL frequently accessed the CNBC for nuclear fuel analysis and stress measurement in feeder tubes and feeder welds.[21]

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[18] More detail on the academic community is provided in the appendices.

[19] There is an informal *quid pro quo* arrangement in which foreign scientists are welcome at the CNBC in return. The trade balance between the number of Canadians accessing USA facilities and USA researchers accessing the CNBC is about equal.

[20] KPMG. "A Report on the Contribution of Nuclear Science and Technology (S&T) to Innovation." Final report prepared for Natural Resources Canada. Fall 2014. See pages v and 136 for the distribution and numbers of faculty. Though they represent only 0.7% of all NSERC-funded faculty, they represent 1.8% of all NSERC Canada Research Chairs, 1.3% of all NSERC Industrial Research Chairs and 2.2% of all of NSERC's Collaborative R&D grants (page 148).

[21] Daniel Banks, Ron Donaberger, Brian Leitch, Ron Rogge. (2014) Stress analysis of feeder bends using neutrons: new results and cumulative impacts. Pacific Basin Nuclear Conference. PBNC2014-186. http://pbnc2014.org/proceedings/html_files/2288.html

2.5.3 Government Clients

In addition to government clients who access the CNBC indirectly through CNL, direct government clients include Canmet, National Research Council (NRC) and the Defence R&D Canada (DRDC). Canmet and NRC typically access the CNBC to advance their R&D work with industry. DRDC typically accesses the CNBC for its own operations, for example, investigating the strength of welds on military ship hulls to manage the aging of the fleet.

2.5.4 Other Stakeholders

In addition to the many user organizations, the following parties have relevant expertise or interests in operations of a neutron beam facility:

- Canadian Nuclear Laboratories (CNL). CNL operates the former AECL Nuclear Laboratories, recently restructured by NRCan as an emerging "national nuclear laboratory,"[22] that provides S&T services to industry and the federal government.[23] In addition to its role as a user of neutron beams described above, CNL has operated the CNBC since 2013, and now employs much of the CNBC's expertise for operating the beamlines and supporting users. CNL has decades of experience operating the neutron source and providing complementary and ancillary services to the neutron beam lab, including engineering design and fabrication of beamlines, radiation protection and safety qualification, and other support services. As of Sept. 2015, CNL is managed by Canadian National Energy Alliance (CNEA), a private sector consortium (see www.cnea.co).
- National Research Council (NRC). NRC operated the CNBC for 15 years (1997 to 2013) and is the owner of the CNBC's beamlines and equipment. NRC employs the balance of CNBC's staff.
- Atomic Energy of Canada Ltd. (AECL). AECL is the owner of the assets managed by CNL, and is responsible to oversee the contract with CNEA to manage CNL. AECL is a crown corporation reporting to Natural Resources Canada (NRCan).
- Natural Resources Canada (NRCan). NRCan is responsible for nuclear policy including the nuclear innovation agenda under consideration. NRCan funds CNL to operate the NRU reactor (today, these funds also cover the CNBC's operations), perform a suite of nuclear S&T projects for federal departments, disposition federal nuclear liabilities, and upgrade facilities.
- McMaster Nuclear Reactor (MNR). MNR is the only other domestic facility with a significant flux of neutrons (described above in section 2.4). To reproduce some of the CNBC's capabilities at MNR, significant upgrades would be required to boost its operating power, operate at full capacity, expand the beam halls, and add a suite of beamlines and ancillary equipment. Boosting neutron flux beyond levels that can be achieved by only increasing the power would be a major project involving a redesign and fabrication of the reactor core.
- Canadian Institute for Neutron Scattering (CINS). CINS is a not-for-profit, volunteer-based organization that represents the Canadian scientific community of neutron beam users and promotes scientific research using neutron beams. See www.cins.ca.

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[22] "Transitioning the CNL S&T Program", Presentation by S. Bushby at the COG Workshop on Long-term R&D Strategic Plan, January 20, 2015.

[23] "The Domestic and International Nuclear Landscape: The Need for an Appropriate Canadian Long-term Nuclear ST&I Agenda", Presentation by W. Kupferschmidt at COG Workshop on Long-term R&D Strategic Planning, January 20, 2015.

3.0 A Virtual Institute for Neutron Scattering (VINS)

3.1 Planned shutdown of the NRU reactor creates a 'neutron gap'

The NRU reactor is Canada's only major neutron source, and is the source for the Canadian Neutron Beam Centre. In February 2015, the Government of Canada announced plans to close the aging NRU reactor in 2018, citing growing costs of repairs and maintenance to ensure reliable operations.[24] CNL desires to maximize value from NRU until then, including the full exploitation of neutron beams for materials research.

A new neutron source in Canada – if one is built – will not be fully operational for a decade or more; this time period is known as the 'neutron gap'. The expectation of a lengthy neutron gap, and the uncertainty whether there will be a new neutron source in the future, presents an immediate challenge for retaining neutron-beam expertise in Canada.

Based on the foregoing policy context and stakeholder analysis, this document assumes that Canada has an interest in retaining neutron beam capability during the neutron gap so that, at a minimum, decisions about a new neutron source and nuclear innovation are not undermined.[25]

3.2 Establishing a virtual institute

The neutron gap places Canada's science and innovation capabilities using neutron beams at risk. By first stabilizing and then growing these capabilities, Canada can boost industry competitiveness directly through the knowledge generated for clients or in Canada's priority areas for S&T, and indirectly through attracting, training, and retaining highly qualified people.

Establishing a VINS that operates in partnership with one or more existing neutron sources is one way to stabilize some or all of this capability for the period beyond 2018. The VINS could then act as a vehicle for the pan-Canadian community to grow by attracting further investment in neutron beam infrastructure, whether at domestic or foreign sources and to sustain a proactive outreach and educational program to foster materials research with neutron beams, to maintain this national capability in a competitive state.

[24] $465M has been allocated for repair and maintenance projects between 2008 and 2016 ("Government of Canada Announces Extension of National Research Universal (NRU) Reactor". News Release. February 6, 2015 http://news.gc.ca/web/article-en.do?mthd=index&crtr.page=2&nid=929189). March 31, 2018 is the planned closure date, according to Bob Walker, former CEO of Canadian Nuclear Laboratories ("The future of NRU and CNL." Community Information Bulletin. February 6, 2015 http://www.cnl.ca/en/home/news-and-publications/bulletins/2015/NRU_decision.aspx).

[25] A neutron gap disrupts materials research with neutron beams: users and clients turn to foreign facilities or withdraw from the field, while the national centre for the national capability is lost. If all capabilities are lost, effective exploitation of a new research reactor for neutron beam will be delayed about 10 years because (1) the new centre will lack experience in managing a user facility operation and will lack guidance for developing optimal, user-aligned functionality, and (2) the need to rebuild the user community.

3.2.1 Mission

The mission of a VINS is to advance science and innovation by fostering the national capability for materials research with neutron beams. It fosters this capability primarily by developing and operating neutron beam instruments in Canada and at some of the best neutron sources worldwide, and making them available for access by industry, government and academic R&D programs.

3.2.2 Impact areas

Neutron beams are versatile infrastructure for Canadians to perform research on materials ranging from fundamental exploration to failure analysis of critical industrial parts, such as engines, pipelines, railroad tracks, and turbines. Through strategic selection of expertise, beamlines, and in-house research, a VINS can expect to tune its widespread impacts to focus on these areas of Canada's S&T strategy[26]:

- Advanced Manufacturing: aerospace, automotive, lightweight materials and technologies, additive manufacturing, quantum materials, nanotechnology
- Natural Resources and Energy: fuel cells, nuclear energy, and pipeline safety
- Health and Life Sciences: biomedical engineering and medical technologies
- Environment and Agriculture: biotechnology

It will impact these areas by enabling the research described in section 2.1.2.

3.2.3 Scope

The scope of a VINS can include all activities instrumental to its mission and purposes that can be conducted either away from the source of neutrons or through 'outstations' at distant neutron sources. These activities may include the following:

- Securing funds and resources
  - Preparing funding applications on behalf of the neutron beam user community, submitted through the owner universities
  - Negotiating agreements with off-site neutron sources
- Performing research, development, and implementation of beamlines, methods and ancillary equipment at outstations
- Operating beamlines and associated equipment, labs and workshops at outstations
- Providing complementary theoretical and computing facilities and expertise
  - Providing specialized scientific IT services
  - Developing turn-key services for industry by integrating experimental and modelling capabilities
- Training, attracting, and retaining expertise
  - In-house research programs in select areas to build capability for the future (e.g. integrated approach to stress analysis)
  - Neutron scattering schools and workshops
  - Student scholarships
  - Research chairs

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[26] Industry Canada. Canada's S&T strategy. "Seizing Canada's Moment: Moving Forward in Science, Technology and Innovation 2014." http://www.ic.gc.ca/eic/site/icgc.nsf/eng/h_07419.html

    - Outreach to potential industry clients and other new users
- Supporting clients and users
    - Assistance in proposal development, analysis and publication of results
    - Travel support to outstations
- Managing the allocation of the resources
    - User proposal review system
    - Commercial services
    - Hosting scientific advisory committees on priorities and operating policies
- Government and stakeholder relations
    - Facilitating community input and discussion
    - Organizing fora for scientific networking and policy discussion
    - Performance analysis and reporting
    - Outreach to the general public
- Other Administration
    - Facilities Management, HR, Finance, Procurement, Health, Safety and Security, including radiation protection

A ‘full-service’ VINS may perform most or all of these activities itself. The Jülich Centre for Neutron Science (JCNS, see text box on following page) in Germany is an example of such a virtual institute, which employs over 170 people in neutron scattering research, development, and beamline operations located at the virtual office and at one domestic and three foreign outstations.

Alternatively, a VINS could be a smaller scale organization that procures many of these services from third-parties such as host neutron sources, partner universities or other research organizations (e.g. National Research Council or Canadian Nuclear Laboratories). In this case, the primary activities of the VINS would be securing and directing use of funds and resources on behalf of the pan-Canadian community, providing user support and coordinating Canadian involvement in developing and operating the outstations.

3.2.4 Caveat: Not intended to replace reinvesting in a neutron source

In the Jülich example, the virtual institute model functions in part because Germany also contributes its own neutron sources for access by the global community. A VINS might not be sustained over the long term unless Canada invests in its own domestic source or substantial funds toward the capital and operating costs of a foreign neutron source.

As discussed in section 2.3, most neutron beam facilities around the world are old facilities, and the several new facilities will not replace the facilities likely to close during the next decades. When foreign partners reinvest in new facilities, Canada will be expected to invest as well by contributing to the capital and operating costs, rather than covering only the incremental costs of ‘Canadian beamlines’, if it does not contribute a source of its own to the global network of sources.

The Jülich Centre for Neutron Science (JCNS)

The Jülich Centre for Neutron Science (JCNS) in Germany was founded when the neutron beam reactor FRJ-2 at the Jülich Research Centre closed in 2006, and the beamlines were transferred to the Heinz Maier-Leibnitz Zentrum (MLZ), which uses the FRM-II reactor at the Technical University of Munich as its source of neutrons.

Today, JCNS offers access to 18 beamlines at three outstations and is developing beamlines for a fourth outstation. It offers German and foreign researchers access to 11 dedicated beamlines that it operates at MLZ, which is located 6 hours' drive away from Jülich. MLZ operates the balance of its beamlines not associated with JCNS. JCNS employs 70 staff at its MLZ outstation.

JCNS offers Germany-based researchers access to a portion of the time on 6 beamlines at two foreign facilities: Institut Laue-Langevin (ILL) in France and the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory, USA. Users from German universities are eligible to obtain funds from JCNS to assist with travel, accommodation and subsistence during their beam time. JCNS employs 4 staff at its ILL outstation and 8 staff at its SNS outstation to assist with development and operation of these beamlines.

The fourth outstation is the European Spallation Source in Sweden, which is scheduled to be fully operational in 2025. JCNS employs 3 staff at its ESS outstation.

JCNS has two research divisions that perform in-house research programs in soft materials, quantum materials, and structures and dynamics of materials. These divisions also perform development of beamlines and methods. Together, these divisions employ over 80 staff.

JCNS supports these activities with a Technical Services and Administration Division, which supports its scientists in designing and constructing instruments, and provides specialized scientific IT services including high performance computing and software development.

In one scenario, Canada could be asked to participate in a USA investment of $1B to build a second target station at its Spallation Neutron Source. A capital contribution of a few hundred million plus a few tens of millions per year toward operations to secure a permanent place as a junior partner could be appropriate. Such a major investment decision would less than, but still comparable to building a new domestic facility. The cost savings would need to be balanced against other factors: academic and provincial co-investment will be more difficult to achieve for a foreign facility, the responsiveness of a foreign facility to Canadian requirements will be lower, and additional time required for multi-lateral negotiations may significantly delay the project and prolong the gap period. The border will add real and perceived barriers that may inhibit Canadian usage, including usage by Canadian industry and government labs; thus, significantly more outreach activities will be required.[27] There will be reduced

[27] It is sometimes suggested to adopt the model for Canadian astronomers and nuclear particle physicists routinely rely on access to foreign facilities. The members of these research communities are specialists whose entire careers may be centered on foreign facilities with an international outlook. World-class astronomy and particle physics facilities often require multinational investments to be at the leading edge of the field. Scientific requirements dictate the geographical location of land-based telescopes. These big-science facilities help to answer fundamental questions about nature that are not the

returns on the investment in areas such as training and retention of highly qualified people within Canada, uptake of technology by Canadian firms, and spin-off benefits (e.g. local taxes and economic activity).

3.3 A Possible Future State for Neutron Scattering in Canada Facilitated by a VINS

Whether or not a Canadian VINS is a full-scale organization like JCNS, the JCNS example is suggestive of what might be done in the Canadian context:

- A VINS is formed as a pan-Canadian effort to succeed the Canadian Neutron Beam Centre as the NRU reactor closes, having active support of the administrations of a dozen or more universities and research organizations.
- The VINS secures funds and resources for capital projects and operating activities from federal and provincial agencies, and other partners.
- The VINS oversees the transfer of beamlines and equipment from the Canadian Neutron Beam Centre to one or more neutron sources.
- The VINS partners with the best and most accessible foreign neutron sources to develop and contribute to the operation of beamlines at these outstations. The VINS provides support to Canadian researchers to access them and hone their talents at leading facilities such the NIST Centre for Neutron Research and the Spallation Neutron Source.
- The VINS partners with the McMaster Nuclear Reactor to serve as the interim domestic neutron source, and invests to boost its power, operate at full capacity,[28] expand the beam halls, and add a suite of beamlines and ancillary equipment. The VINS then operates the beamlines as an outstation easily accessible by universities for training students. The VINS makes the beamlines available to foreign researchers as well as a contribution toward the global network of neutron beam facilities. The VINS studies feasibility of redesigning the reactor core to boost neutron flux further.
- Partner universities attract research chairs who will train students and perform research in the impact areas using the facilities made available through the VINS.
- The VINS and its partners perform research and development of beamlines and methods to enhance capabilities and ramp them up toward a new domestic neutron source.
- The governance of the VINS keeps university administrations engaged with the community and facilitates the formation of a unified voice regarding major investments to construct a new neutron source for Canada.

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priorities of any one country. In contrast, the composition of the neutron beam user community and the nature of the problems studied are quite different. The neutron beam user community is largely composed of casual users that require a significant degree of support. These users come from industry, government and universities for whom the barrier to access foreign facilities is significantly higher. A world-class neutron beam facility is within Canada's ability to handle as a national investment. There is no possibility that a reactor with a world-class neutron flux will become obsolete over its 50-year lifetime, because physical laws determine the upper-limit of flux. A neutron beam research facility can be built in Canada since scientific requirements do not restrict geographical location. A domestic neutron beam facility enables the entire spectrum of research, from fundamental to applied, while aligning research preferentially to address priorities in Canada's S&T Strategy.

[28] 24/7 instead of 8 hours per day, 5 days per week

3.4 Funding Framework

3.4.1 Cost planning

Figure 1 illustrates four phases of activity to implement a scenario like that described in 3.3:

1. Start-up the organizational framework (years 1-5) and build expertise and R&D programs at the home base reaching $1-2M/yr (years 4-10).
2. Establish the first outstation (years 3-14) with several beamlines as a user facility with operations of a 'CNBC-like' program at $3-6M/yr, plus $5-10M/yr for a contribution to the operating cost of the associated neutron source. In addition, there will be capital costs of building several beamlines at (or moving and adapting beamlines to) the outstation ($3-8M each).
3. Establish secondary outstations (years 6-18) with smaller programs to enable Canadian access to specialized capabilities not available at the primary outstation. These are assumed to have similar but proportionate costs for capital and operations.
4. Ramp-up toward a new neutron source (years 8-20+). If Canada invests in a new neutron source, whether in a domestic facility or a foreign partnership, an extensive R&D program to develop and build beamlines and equipment will be needed (e.g. $4-8M/yr to develop and build 12 'day-one' beamlines during more than a decade of designing, constructing, and commissioning a neutron source).[29] This R&D program could be divided between activities at the home base and at the outstations.

In all, activities during the neutron gap period could plateau over $20M/yr (figure 1).

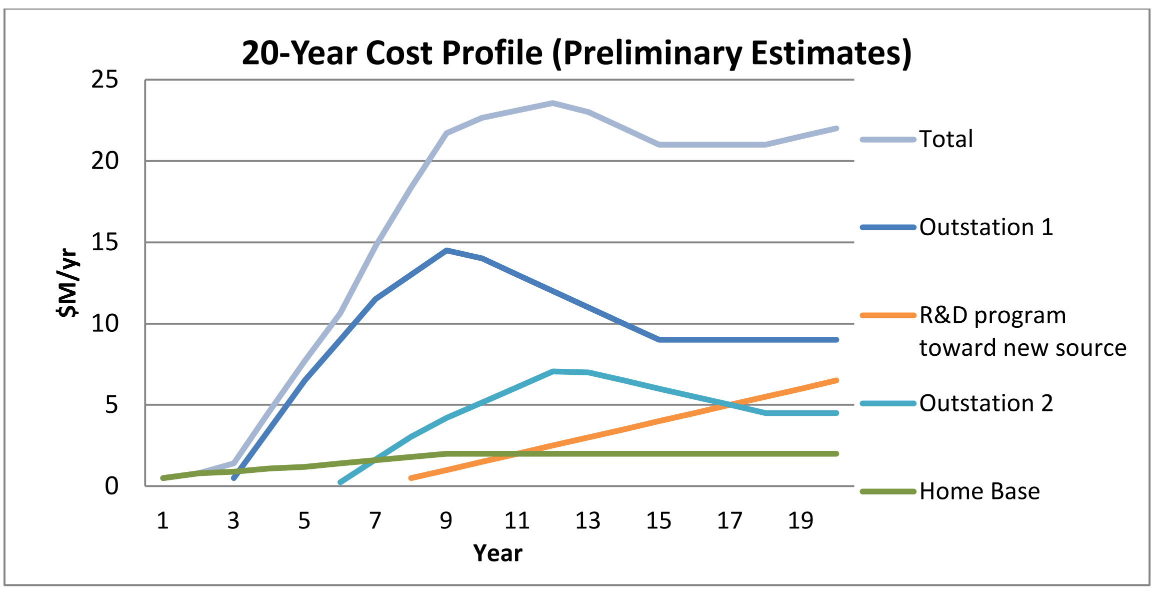

Figure 1 Preliminary cost projections over 20 years, based on table 1.

[29] Given that some of the beamline development at outstations would be transferable to a new source, the incremental 'ramp-up cost' of a new source may not appear as large as if it were a stand-alone activity.

Table 1 Preliminary order-of-magnitude cost estimates of on-going operations and capital projects. Capital costs are expressed as estimates of activity that would be sustained over several years to complete multiple sub-projects in close succession. Actual costs will depend heavily on terms negotiated with neutron sources and the selection of funded activities.

	On-going Operations ($M/yr)	Capital Projects ($M/yr)
Home Base	1-2	-
Outstation 1 (primary source)	5-10	-
Outstation 1 (primary beamlines)	3-5	3-6
Outstation 2 (source)	2-4	-
Outstation 2 (beamlines)	1-2	1-2
R&D program toward new source	1-2	3-6
Total	**13-25**	**7-14**

Some ‘seed’ or venture funding from the initial partners will be needed for pre-start-up phase activities before the VINS is officially formed, and possibly into the first year or two until outside funding is received. Pre-start up activities may include the business and budget planning needed to secure the support of partners, stakeholder consultations, negotiating roles and responsibilities, and scope of mission. The expertise for business planning, grant applications, negotiating with neutron sources, and feasibility studies during pre-start-up and the first few years might be procured initially from stakeholders via agreements for consulting or secondments, until the VINS recruits its own experts.

Table 2 estimates the cost of the home base in the first five years. The VINS will need to recruit an executive director in year 1, and over time an operations manager, communications officer, and an administrative assistant. The executive director will need to travel for community and government engagement. Office space and access to central services (e.g. security, IT, finance) will need to be procured from the host institution. Special overheads include administrative costs above and beyond what a host institution would typically provide. These may include recruitment costs, graphic design and communications, sponsoring or hosting events, and other outreach activities. Direct support for R&D activities at the home office in the first five years could include user support (including travel to outstations, an online proposal system) and attracting research chairs in theory and modelling.

Table 2 Preliminary estimates of cost of activities at the home office over the first five years, not including costs directly attributed to outstations.

Home Base	Year 1	Year 2	Year 3	Year 4	Year 5
Administration (Pay and Benefits)	100	250	350	400	400
Consulting or Secondments	200	400	200		
Recruited Experts (Pay and Benefits)			150	300	300
Travel	25	30	35	40	40
Rent and central services	25	50	75	100	100
Special overheads	100	50	50	50	50
User support		20	40	80	160
Research chairs (Pay and Benefits)				150	300
Total	**450**	**800**	**900**	**1120**	**1350**

3.4.2 Funding sources

Table 3 Possible funding sources

	Possible Funding Sources	Home Office	Domestic Outstation	Foreign Outstation	Use of Funds
1	Canada Foundation for Innovation (CFI)	✓	✓	✓	Capital, O&M
2	Provincial matching of CFI	✓	✓	-	Capital, O&M
3	Direct federal funding	✓	✓	✓	Capital, O&M
4	Federal regional development agencies	✓	✓		Start-up, Capital
5	Host university (in-direct costs of research)	✓	-	-	Start-up, O&M
6	Nuclear innovation agenda	-	✓	✓/-	O&M
7	R&D services for research partners	-	✓	✓/-	O&M
8	Nuclear and non-nuclear commercial clients	✓	✓	✓/-	O&M
9	Funding envelope for new neutron source	✓	✓	✓	R&D
10	Nat. Sciences and Eng. Research Council (NSERC)	✓	-	-	R&D

✓ indicates a possible funding source. ✓/- indicates location may present additional challenges to revenue from this funding source. O&M = Operations and Maintenance. R&D = Research and development activities.

The table lists possible funding sources, which are summarized as follows:

1. The main academic funding source would be the Canada Foundation for Innovation (CFI), initially for capital projects through the CFI Innovation Fund at outstations that would subsequently qualify for operating funds through the Major Science Initiatives (MSI) Fund. CFI usually contributes up to 40% to any project. In the case of MSI, the matching funds can come from any source.
2. Matching funds up to 40% are often provided by the host province.
3. Federal departments can directly support Canadian participation in international projects (e.g. NRC and CSA contribute international partnerships for facilities for astronomy and space research). NRCan and Industry Canada are the most likely federal departments to consider maintaining a Canadian neutron beam competency by support research infrastructure within its mandate.
4. Federal regional development agencies, such as Western Economic Diversification or FedDev Ontario may be sources of funds for some start-up costs, such as feasibility studies in anticipation of large capital funding applications.
5. The host university might cover some of administrative costs of maintaining the home office through in-kind contributions by providing office space and access to central support services. Over time, the host university may be able to recover its contributions through “indirect costs of research” programs from the granting agencies. The host university, with its partners, may need to provide seed funding to cover some start-up costs in the first two years while sustainable funding sources are pursued.
6. The nuclear innovation agenda under consideration – if it materializes in the form envisioned by the Nuclear Leadership Forum – could be a source of funds for operating nuclear research facilities as well to support costs of research program that may access these facilities.

7. Research partnerships could result in-kind and cash income from projects such as neutron imaging services for academic partners, providing access to governmental research bodies, participating in research partnership programs (e.g. funded through NSERC or Networks of Centres of Excellence).
8. Commercial projects for clients in the nuclear-sector might include stress analysis and other R&D services sponsored by the nuclear power industry (e.g. the CANDU Owners Group, or foreign utilities). Commercial projects could include sub-contracts through CNL for services to federal government departments.
9. If Canada invests in a new neutron source in the future, the scope of the funding envelope could include ramp-up research and development activities that foster capability so that Canada will be ready to make full use of the source as soon as it is available. Such activities were included in the scope of the funding announcement for the Canada High Arctic Research Station.[30]
10. The Natural Sciences and Engineering Research Council (NSERC) focuses on research activities[31] at universities and research partnerships with industry. NSERC may be a source of funding for research chairs and other faculty that might be jointly appointed with the VINS and a university. Users of the VINS will rely heavily on NSERC for funding their research programs to hire students and operate their labs.

3.5 Governance framework

The governance of a VINS in Canada should incorporate lessons learned from the CNBC and other major scientific facilities in Canada. While the CNBC has been the focal point of a national research community that it has helped to foster, a significant weakness in its 'user facility model' is now apparent. A major user facility cannot be sustained without either a direct government mandate to operate national facilities[32] or a means for users to cover the costs of their access, neither of which is currently in place. The research community has been and wants to be involved in paying for their access.[33] The absence of a strong university voice to secure such funds reflects two key factors: (1) previous funding arrangements achieved by the researchers via the Canadian Institute for Neutron Scattering (CINS) did not sufficiently engage university administrations, and (2) the diffused interests among many organizations and small proportion of 'professional neutron scatterers,'[34] whose careers critically depend on neutron beams, have not led to a natural champion to act on behalf of the community.

The emerging model for major scientific user facilities in Canada is to be owned and operated by the academic sector and funded mainly by the granting agencies and other government sources. The CFI is

[30] In August 2012, the government announced plans to spend $142.4 million over the next six years on construction, equipment and start-up costs for the facility and $46.2 million during the construction period on its science and technology research program. http://pm.gc.ca/eng/news/2012/08/23/canadian-high-arctic-research-station.

[31] Since the moratorium on its MRS program in 2012 and reductions to its RTI program, NSERC has had a declining role in funding infrastructure.

[32] All other major neutron beam facilities are operated as user facilities and directly funded by governments through organizations. In Canada, a comparable example is the NRC which is mandated by law to operate federal astronomy facilities.

[33] See footnote 16 for past arrangements. A collective funding mechanism for academic access is desired because individual grants are too small to achieve significant cost recovery through direct user fees. In February 2014, CINS applied via McGill University to the CFI Major Science Initiatives Fund for 40% of the CNBC's operating cost. The application was deemed ineligible because the CNBC is affiliated with a federal agency.

[34] In contrast to 'professional neutron scatterers', are the majority of researchers in the neutron beam community who apply many techniques to solve a problem, and who access neutron beams when needed with assistance from CNBC expertise.

emerging as the lead funder of major scientific infrastructure, for both capital and operating costs, a role that was confirmed in the 2015 federal budget with $1.33B over six years for "the ongoing operations and maintenance needs of national research facilities" among other things.[35]

Today, the CNBC is the only academically-oriented user facility[36] that is not operated by the academic sector, apart from federal astronomy facilities due to provisions of the NRC Act. TRIUMF, SNOLAB, and Compute Canada are operated by consortia of universities. The CLS and Ocean Networks Canada (ONC) are operated by non-profit corporations that are wholly-owned subsidiaries of their host universities (U. Sask. and U. Vic. respectively) but are also affiliated with other universities. Smaller facilities are typically operated by their host universities.

In summary, university administrations need to be formally engaged in securing resources for and in on-going governance of user facilities that primarily serve academic researchers. Specifically, academic ownership of such facilities is critical to securing both capital and operating funds from the CFI, which then can be used to leverage matching funds.

Positioning Canadian neutron beam resources within the academic sector via a university-owned VINS addresses the critical issue of eligibility for CFI funding.

The governance of the VINS should reflect a pan-Canadian approach, while reflecting the strong academic interests. The VINS could be formed initially as a consortia or joint venture of a few key universities that seeks to expand to include all universities and other research organizations with significant activity in neutron scattering.

3.5.1 Roles and responsibilities

The consortia members control the VINS through appointing members to the board of directors via majority vote cast by the Vice Presidents of Research or a designate. Members may participate in discussions facilitated by the VINS regarding research priorities and strategies for securing resources. Member should support the consensus positions to ensure that the academic community speaks with one voice.

A lead university should be identified to coordinate efforts, guide initial formation of the VINS, and host the home office. The lead university will also channel funding applications prepared by the VINS to the CFI and other bodies appropriate (i.e. the VINS itself may not be eligible to submit proposals directly).

To ensure that the VINS is operated as a pan-Canadian effort, the board of directors is appointed based on expertise and governance experience, rather than to represent the interests of individual institutions. The board would be responsible to ensure that adequate funds are available to cover all liabilities, so that no costs for its activities are passed on to the members. The board would have fiduciary responsibility for the use of funds and operations of VINS facilities, including activities at the outstations.

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[35] http://www.budget.gc.ca/2015/docs/bb/brief-bref-eng.html

[36] Not only does the CNBC support a primarily-academic community of researchers, but the CNBC also supports the universities' education mission by providing graduate students with one-on-one, hands-on training in conducting the experiments. In addition, the CNBC hosts summer schools open to all students, and hosts groups of students as part of graduate courses at Queen's and McGill.

3.5.2 Management framework

A full-scale VINS needs both scientific leadership and strong project management and operations management, similar to other major scientific facilities (e.g. TRIUMF, CLS). As a user facility, it needs a culture that values helping others to advance their research. These factors suggest the VINS should be managed separately from the host university.

As illustrated below, external scientific advisory committees are needed to inform scientific priorities, complementing the board's expertise on good governance of scientific facilities. The R&D program, focused on beamlines and technique development, would best conducted as a collection of projects, each under a project manager. Activities at the outstations, in contrast, represent the on-going operations of the user facilities and would use a traditional organizational structure. Technical services personnel would support both R&D projects and operations. Administrative staff would assist in operating the VINS in areas beyond what can be provided by the central administration of the host university.

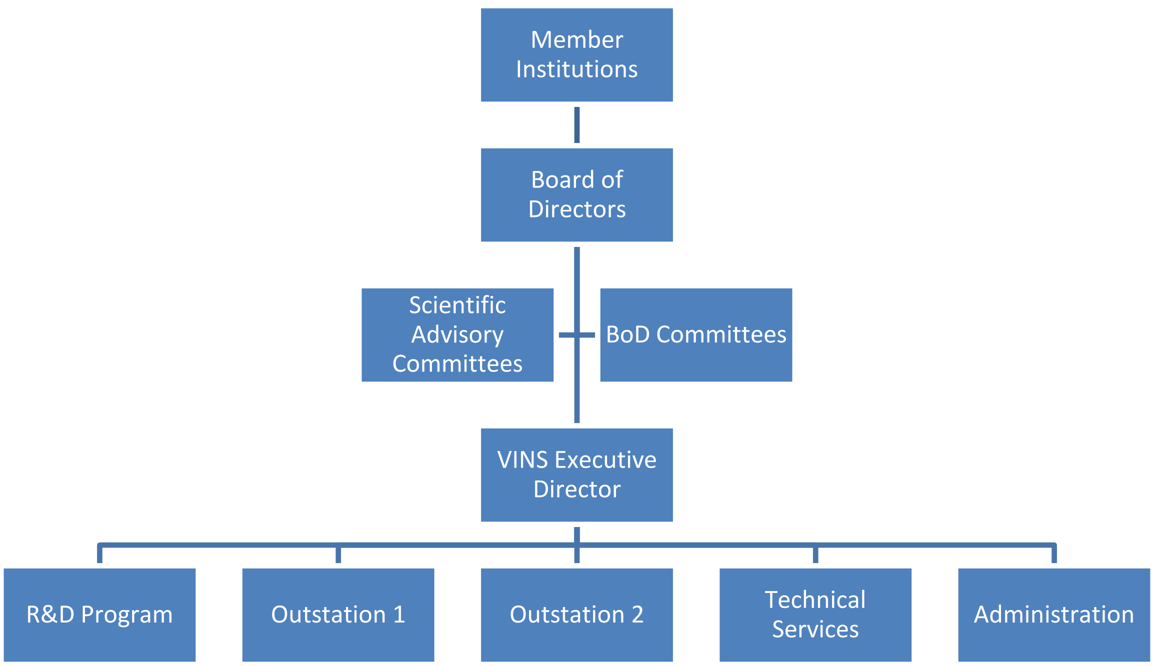

Illustration: Organizational structure of a full-scale VINS

3.6 Timelines for implementation

The following are significant factors in setting an implementation schedule:

- Government decisions about a nuclear innovation agenda or a new research reactor are not imminent, but could be made within a few years.
- CFI Innovation Fund holds competitions approximately every two years for large capital projects. The next competition may be expected in early 2016 following conclusion of CFI's current consultation on its fund architecture. CFI may take a year to complete the competition and award funds (2017).
- The NRU reactor is scheduled to close March 31, 2018.

- Executing capital projects to build beamlines can take up to several years. Moving beamlines from NRU and adapting them to a new source are significant projects, though they may take less time.
- Following construction of beamlines, the next CFI Major Science Initiatives (MSI) Fund competition could begin in 2020 to award operating funds for 2022-2027.

The first window of opportunity to secure funds for a VINS project is the next CFI Innovation Fund competition, which could finance building beamlines and equipment or moving and adapting them to another neutron source. To compete credibly in the competition, a lead university must be identified, discussions with potential partner sources should be held and a plan created for the scope of a CFI–funded project within 6 months. This short timeframe will require that discussions of the VINS should be held parallel to the CFI application.

Initially, a small-scale version of the VINS could be formed with seed funding to establish the core structure and enable it to pursue funding opportunities to be able to perform the VINS's primary activities. Until those resources are available, the VINS can begin to establish its place in the community through associated activities:

- facilitating community input and building a network of participating universities
- organizing fora for scientific networking and policy discussion
- sponsoring or organizing neutron scattering schools and workshops
- building the community through awarding student scholarships or attracting research chairs to member universities
- providing basic user support (e.g. sponsoring travel for students of member universities to conduct experiments at neutron beam labs, assistance in proposal development, analysis and publication of results)

With a successful CFI Innovation Fund award in 2017, the VINS will have a suitable context to begin performing these activities in 2018 during the neutron gap.

Appendix A – The Neutron Beam Community

Each year, over 200 scientists, engineers, and students from universities, government labs, and industry participate in research depending on access to our six neutron beam lines. Over a five-year period, CNBC research participants include more than 700 individuals from over 60 departments in over 30 Canadian universities and from over 100 foreign institutions in over 20 countries. The CNBC enables industrial research in sectors such as nuclear energy, aerospace, automotive, oil and gas, defence, and primary metal production.

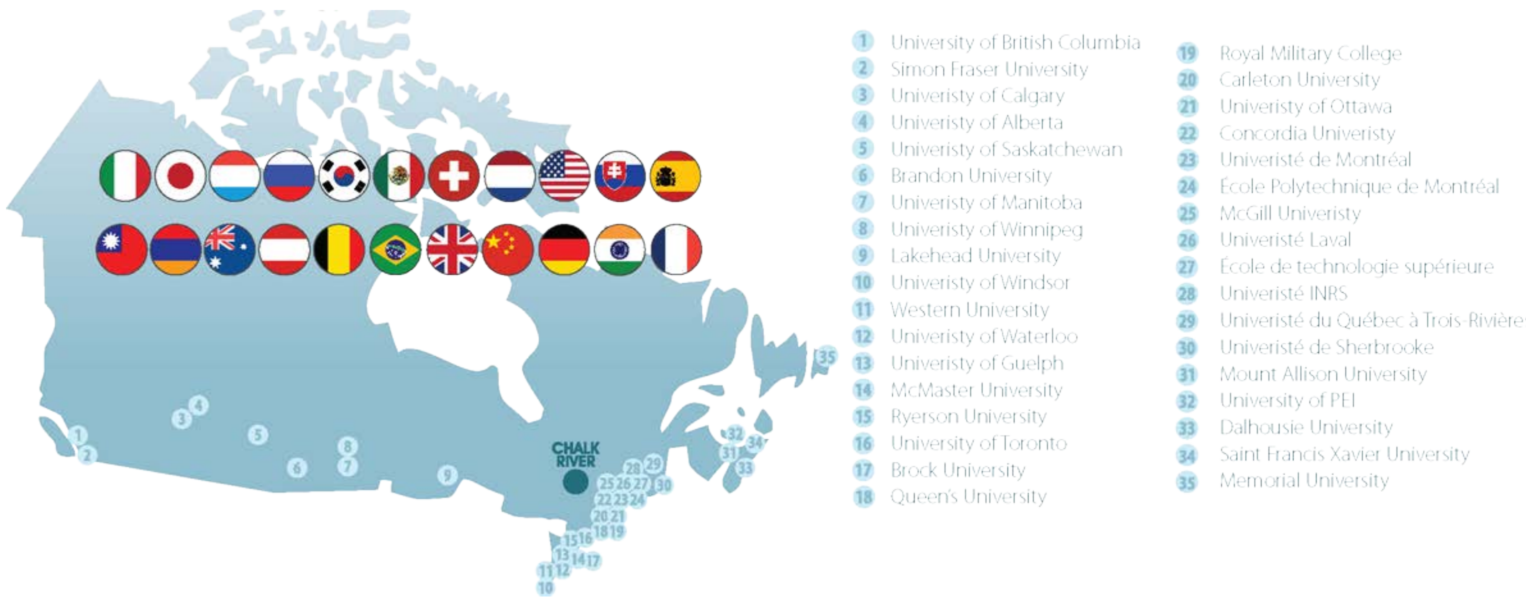

Figure 2 Geographic distribution of 35 participating universities over 5 years, as well as 22 countries of foreign institutions, represented by flags.

The CNBC typically provides more than 80% of its beam time for access by external users. Canadian academics are the largest user category and directly use about half of the available beam time each year. About 100 Canadian academics each year are able to participate in research depending on access to foreign facilities, free of charge, because the CNBC grants access to foreign users in exchange.

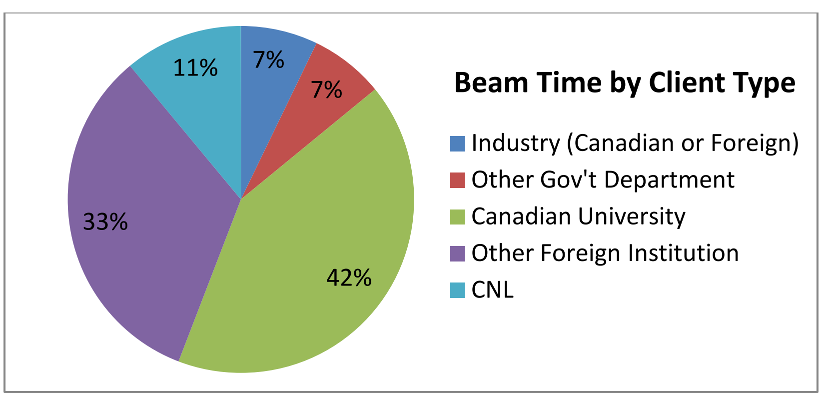

Figure 3 Fractions of neutron beam time allocated to categories of external users (FY2014-15 data). Academics use a large majority of beam time. As shown in Table B1, academics comprise about 2/3 of all foreign users. About half of the beam time granted to industry is for collaborations involving both academics and industrial researchers.

Table B1 Users over four years (FY2011/12-2014/15). Users include researchers who proposed the research granted beam time or were present for the experiment.

Sector	Canadian	Foreign	Total
Academic	145	120	365
Industry	10	13	23
Government	34	26	60
Total	**189**	**159**	**348**

Table B2 Research Participants over four years. Research Participants include users plus co-authors of papers arsing from the research.

Sector	Canadian	Foreign	Total
Academic	208	216	424
Industry	11	16	27
Government	44	128	172
Total	**263**	**360**	**623**

The CNBC's academic clients cover a broad spectrum of disciplines. In 2014, for example, the CNBC's academic research participants consisted of 88 individuals from 30 departments in 19 Canadian universities, distributed across disciplines, as illustrated in Figure 4.

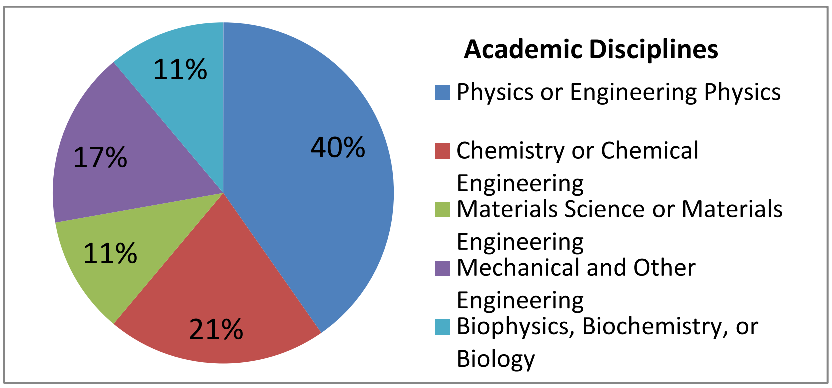

Figure 4 Distribution of Canadian academic research participants across disciplines

Higher education's greatest contribution is in training students in essential S&T skills.[37] Most research professors that access neutron beams for studying materials rely on the local expertise of the CNBC.[38] Typically, over 30 students and postdocs per year visit the CNBC to use the beamlines for their research.[39]

[37] "The research conducted in our universities and teaching hospitals educates students in advanced fields of knowledge. Some will become the researchers of tomorrow. Others will follow a range of practical pursuits in all sectors of the economy." Industry Canada. *Mobilizing Science and Technology to Canada's Advantage*. 2007. pp.35-36.

[38] For example, most research professors that are neutron beams users are experts in particular problems in engineering, physics, chemistry, or biology, and in several methods of studying materials that underlie these problems, but most do not use neutron beams frequently enough to fully specialize in applying neutron beams to study materials. With nearly every academic proposal, one or more students are advancing their research skills through interacting with local experts regarding the conceptual design, sample preparation, conducting the experiment, or interpreting the data and publishing the results.

[39] In 2011-2014, there have been 242 visits by 137 students and 20 post-doctoral fellows for research and education purposes, many of whom visited more than once.

Appendix B – Key Universities

Following is a list of key universities with interest in neutron beams. Names of key principal investigators are listed[40]. These researchers have collectively benefitted from about $25M-worth of access to the CNBC over 5 years to advance their research programs, free of direct charge.

McGill University

McGill has benefitted from $5.4M-worth of access to the CNBC over 5 years to advance the research programs of Stephen Yue (Materials Engineering), Chris Barrett (Chemistry) and Dominic Ryan (Physics). Because Prof. Ryan was President of CINS, he held the NSERC Major Resources Support grant for 2007-2012 that supported access to the CNBC, and McGill administered the funds valued at $1.3M/yr. McGill supported the grant renewal application in 2012 and a recent application to CFI for $4.4M/yr in operating funds for the CNBC. The McGill Centre for Physics of Materials sponsors a physics graduate course on research techniques (PHYS-659) and relies on the CNBC for hands-on demonstration of neutron scattering methods.

McMaster University

McMaster has benefitted from $6.2M-worth of access to the CNBC over 5 years to advance the research programs of Bruce Gaulin (Physics), Graeme Luke (Physics), Maikel Rheinstadter (Physics), Cecile Fradin (Physics), John Greedan (Chemistry), and Peidong Wu (Mechanical Engineering). Prof. Gaulin is a former President of CINS and of the Neutron Scattering Society of America. The CNBC complements facilities at the Brockhouse Institute for Materials Research of which he is the Director. The CNBC recently assisted Prof. Gaulin to build a CFI-funded neutron beamline at the McMaster reactor, and is now helping to build a second beamline funded at $7M by CFI. McMaster's AVP-Research, Fiona McNeill, is a former neutron scatterer. McMaster also has broader interests in nuclear S&T through its nuclear engineering and nuclear medicine programs.

University of Saskatchewan

The University of Saskatchewan (U of S) has benefitted from $330K-worth of access to the CNBC over the past two years to advance the research programs of Ian Burgess (Chemistry). Although new to neutron beams, U of S has a strong record in materials research via the Canadian Light Source (CLS), and is a key player in helping the province to achieve its goal of expanding its expertise and capabilities in nuclear S&T. In 2009, the U of S formally expressed interest in a hosting a neutron source on its campus that would complement the Canadian Light Source[41]. In 2011, the provincially-funded Fedoruk Centre was formed as a subsidiary of U of S to place Saskatchewan among global leaders in nuclear research, development and training. One of the Centre's activities is to fund research in Saskatchewan that uses nuclear-based methods, such as neutron beams.

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[40] E.g. those who accessed the CNBC in FY2011-12 to FY2013-14.

[41] "The Canadian Neutron Source." July 2009. Accessed from: http://cins.ca/reports.html.

University of British Columbia

UBC has benefitted from $2.4M-worth of access to the CNBC over 5 years to advance the research programs of Warren Poole (Materials Engineering), Lukas Bichler (Materials Engineering), Chad Sinclair (Materials Engineering), Doug Bonn (Physics) and Walter Hardy (Physics). The CNBC supports MAGnet, an NSERC network led by Prof. Poole, and recently hosted a post-doc to support MAGnet research projects requiring access to the CNBC. The CNBC supported projects led by Prof. Bichler as part of AUTO21, an NCE network.

Dalhousie University

Dalhousie University has benefitted from $1.5M-worth of access to the CNBC over 5 years to advance the research programs of Ted Monchesky (Physics and Atmospheric Science), and Paul Bishop (Process Engineering and Applied Science). The CNBC complements facilities such as the Institute for Materials Research. The President of Dalhousie, Richard Florizone, is familiar with the CNBC and the need for a new research reactor for Canada, having recently served as VP-Finance at U of S, where he participated in the province's uranium development partnership project, articulating the value of materials research with a research reactor, provided executive support for the establishment of the Sylvia Fedoruk Canadian Centre for Nuclear Innovation, and discussed the possibility of a new "Canadian Neutron Source" at the U of S with CINS members at their annual general meeting in Saskatoon in 2010.

University of Alberta

The University of Alberta has benefitted from $2.8M-worth of access to the CNBC over 5 years to advance the research programs of Hani Henein and David Mitlin (both from Chemical and Materials Engineering). The CNBC complements facilities at the National Institute for Nanotechnology. The President of U. Alberta, Indira Samarasekera, is a former neutron scatterer. U. Alberta has shown leadership in supporting user facilities sited elsewhere by contributing to the Canadian Light Source.

Queen's University

Queen's has benefitted from $4.0M-worth of access to the CNBC over 5 years to advance the research programs of Lynann Clapham (Physics), Rick Holt (Emeritus, Materials Engineering), and Mark Daymond (Materials Engineering). Prof. Clapham is Associate Dean (Academic). An engineering graduate course on research techniques (MECH-851) relies on the CNBC for hands-on demonstrations. Queen's U. also has broader interests in nuclear S&T through its nuclear engineering programs.

Western University

Western has benefitted from $2.4M-worth of access to the CNBC over 5 years to advance the research programs of David Shoesmith, and Clara Wren (both from Chemistry). Western University also successfully led a CFI-funded proposal, supported by 12 universities, to build a $2.4M neutron reflectometer at the CNBC, which was completed in 2007. The CNBC operates the reflectometer as part of its suite of 6 beamlines for access by the user community. The CNBC complements facilities at Surface Science Western.