The Canadian Neutron Initiative: Planning for the Future of Neutron Scattering in Canada

by Thad Harroun

There's a balance to strike between the federal government's economic responsibilities and the scientific research it funds. Since 2007, and amended in 2014, Canada's federal government has adopted five key Research Priorities, with several additional Focus Areas to assist with it's decision making [1]. The recent release of the report on science funding landscape, Canada's Fundamental Science Review, known generally as the Naylor Report, shows that discovery research across all the granting councils is badly underfunded, and there is an acute need for the funding of major research facilities [2]. Additional calls from Universities Canada have urged the government to establish a dedicated support fund for international research collaboration, and additional support for research infrastructure through the Canada Foundation for Innovation [3].

One common thread running through most of these federal research Focus Areas could be summarized as research in materials. Newly designed materials, and re-purposed well known materials, are needed for biomedical technologies, advanced manufacturing, and clean energy systems. The physical characteristics of these materials under varied conditions must be understood to advance the technology and make new discoveries. The grand challenge is to fully characterize their properties at atomic and molecular scales, for which Canadian researchers need a complete 21^{st} century toolkit for probing materials. There are many probes available to the material scientist to study the nano and atomic scales; electrons, X-rays, and neutrons, each with their own physical capabilities, limitations, and overlapping complementarity.

The advancement of our understanding of the materials around us is determined in large part by the capabilities of our scientific equipment. And as discussed in the recent commentary of Charles Day, Editor of *Physics Today*, on the extraordinary advancements of electron microscopy of the last 10 years, advances in scientific equipment are driven by robust funding of the research topics that equipment is used to study [4]. When scientists are properly funded to pursue frontiers of knowledge in particular area, instrumentation designers will rise to the challenge. Advances in instrumentation lead to the discoveries of tomorrow, and eventually, this equipment becomes the necessary routine measurements at the beginning of every new research direction.

Summary

The Canadian Neutron Initiative is a University-led group with a plan to address Canada's looming shortage of neutron beams for materials research when the National Research Universal (NRU) reactor at Chalk River closes in March of 2018.

For many Canadian researchers, a crisis is at hand with the final closure of the venerable NRU reactor at the Chalk River Laboratories in March 2018. NRU has been Canada's primary domestic source for research using neutron beams for six decades. Six research instruments of the Canadian Neutron Beam Centre, used by a community of over 800 researchers and students over the past five years for the understanding of such things as electrolytic corrosion, topological quantum materials, and cell membranes, will be shuttered along with the reactor. Meanwhile, $8 billion has been invested around the world since the year 2000 in new neutron beam instrumentation or new neutron sources. While an, the world is renewing their important scientific tool, Canada is losing it.

The Canadian Institute for Neutron Scattering (CINS) represents researchers using neutron beams for materials research. Research by CINS members touch on every federal science priority. Eighty-two (82) Canadian researchers participated in a recent CINS survey in which one third self-identified as Material Scientists, another third as researchers in Physics, and the rest considered their research to be in the fields of Chemistry, Biology, or Engineering, with 3% choosing 'Other'. All respondents considered neutron scattering as 'very' or 'somewhat important' for advancing their research. The interested reader can find many examples of research advances by CINS members in the other articles in this issue of Physics in Canada, as well as highlights presented at cins.ca/discover.

More importantly, we found that 55% of the planned experiments by CINS members in 2017-2018 will be to the NRU, even in its last year of operation. The Canadian Neutron Beam Centre will continue to welcome over 200

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industrial and academic researchers, graduate and undergraduate students before winding down operations [5]. The demand for neutrons to advance the research of CINS members remains strong. With the closure of the NRU reactor, the research community must act now to prevent the complete loss of an important tool in the researcher's toolbox by establishing a program to ensure that Canadians researchers can effectively use other neutron sources in a world of increasing demand for neutrons.

THE CANADIAN NEUTRON INITIATIVE

The Canadian Neutron Initiative (CNI) is a response to the urgent challenge, aiming to provide continued access for Canadians to this critical scientific tool for the near and medium term. The CNI would establish a new leadership framework of Canada's capacity for materials research with neutron beams, by building on existing national and international resources. The Initiative will ensure Canadians can readily access neutron beams for world-class research and innovation in materials, as well as training students for highly-skilled careers [6].

The CNI is a university-led framework, driven by the University of Saskatchewan and McMaster University, in close collaboration with CINS and the Canadian Nuclear Association. As a pan-Canadian initiative, it is supported by other universities and organizations and presently continues to gather broad support. For the University of Saskatchewan, which has had great success in establishing a large scale user-facility for materials research in the Canadian Light Source synchrotron, the complementary technique of neutron scattering is a value-added proposition to the development of Saskatchewan as a leader in nuclear research for economic benefit. The Sylvia Fedoruk Canadian Centre for Nuclear Innovation at the University of Saskatchewan has already made great investments in the fields of nuclear medicine and nuclear policy research, has invested in materials researchers using neutron beams, and is now contributing its expertise to the CNI.

McMaster University has the largest group of materials researchers in Canada who use neutron beams and hosts the McMaster Nuclear Reactor (MNR), which will be Canada's most powerful multi-purpose research reactor by far at the time of NRU's closing. In the past several years, McMaster has invested heavily in expanding its physics, nuclear, and materials R&D capabilities at the MNR, such as the planned McMaster Intense Positron Beam Facility for materials surface research, and the unique High Level Laboratory Facility for handling large quantities of radioactive specimens.

The MNR is also endeavouring to help meet some of the demand for neutron beams when NRU closes. Through the Brockhouse Institute for Materials Research, construction is well underway for the $9M Canadian Foundation for Innovation and Ontario Innovation Trust funded 'MacSANS', a dedicated small angle neutron scattering beamline in Canada on beam port 4 of the MNR. The MNR has just enough space to operate perhaps two additional diffraction instruments, such as a powder diffractometer and a reflectometer.

University of Saskatchewan and McMaster University are natural leaders for the CNI as a pan-Canadian initiative that will address the loss of NRU for all Canadians across two time horizons. For the next decade, the CNI must focus on coordinating access to leading neutron-beam facilities abroad while fully exploiting domestic, university-based capabilities, including the MNR. By retaining and investing in Canadian capabilities, the CNI will also be able to assist materials researchers to participate in national decision-making processes surrounding large-scale research infrastructure, which could include a new research reactor for 2030 and beyond. Any such new reactor will include contributions from other stakeholders such as the nuclear power, manufacturing and medicine sectors.

Foreign Partnerships

With the loss of NRU, Canadian researchers will immediately need more access to world-leading neutron beam facilities abroad. Currently, over one-third of experiments originating in Canada are conducted in the United States, with a smaller 12% conducted in Europe. There are many hurdles to gain access to these facilities, chief among them is the current over-subscription rates, which can be as high as 4 times for some instruments. Furthermore, although new facilities are being built, the global supply of neutron beam time is shrinking overall because many old facilities have closed or are expected to close in the next 15 years. Another concern is the exclusion of applications from non-contributing countries at European facilities, especially the flagship Institut Laue Langevin (ILL) laboratory in France, and the new European Spallation Source (ESS) now under construction. It's not possible that the global capacity can accommodate an increase demand originating from Canada for neutron beam time without special intervention.

Several of the world's leading neutron scattering laboratories, including the ILL and the facilities in the USA, have expressed a keen interest in establishing a formal partnership with Canada. Funding and managing memberships in foreign facilities are therefore fundamental components of the CNI. Canada's experience with such a partnership consists of a CFI-funded contribution of $15M via McMaster University toward the construction of the SEQUOIA high resolution spectrometer and VULCAN engineering diffractometer at the Spallation Neutron Source at Oak Ridge National Labs (USA), which was exchanged for preferred access by Canadians for a portion of the beam time. However this agreement expires in 2018, and since it represents a significant fraction of the planned trips to the US by Canadian researchers this year, the expiry will add to the stress of finding beam time for experiments originating from Canada.

A new partnership that invests Canadian federal research dollars directly into a foreign laboratory could take several forms, but would certainly result in beam time set-aside specifically for

Canadian applicants on a much wider selection of instruments. This would ease the burden considerably for Canadian researchers, and open the door to others who are neutron scattering novices. In addition, we have identified several other important considerations that must go into an effective partnership agreement, such as travel support, development of ancillary equipment and local instrumentation expertise.

For CINS members, our 2017 survey revealed that the best instrument for their research goals, along with highly knowledgeable local collaborators, were the top concerns when planning a neutron laboratory visit. Reactor and spallation-based neutron sources offer a variety of means of neutron beam delivery; constant or pulsed flux, cold or thermal in energy. Thus, despite the broad overlap in experimental techniques available between facilities, the true strengths within the suite of instruments differ somewhat. As a result, many CINS researchers who use neutron beams frequently have a favorite instrument, with which they are most comfortable and have invested considerable time to understand its capabilities and quirks. For an occasional neutron beam user who may need access once every two or three years, accumulating this knowledge is more difficult. A central coordinating hub can help Canadians at any level of experience to plan, propose, and execute their experiments. The support and knowledge offered by local expertise is invaluable to successfully complete an experiment in the allocated beam time. The coordinating hub will ensure that there are local contacts at the foreign facility that will help guide Canadian visitors through their stay and experiments, and provide training on the data collection, analysis and archiving software.

Most facilities have invested heavily in special ancillary equipment including sample environments, such as cryostats, high magnetic fields, or liquid sample cells. Access to these sample environments is crucial to leverage the unique properties of neutrons to gain knowledge unavailable from other techniques. The neutral charge of the neutron and its weak interaction with many common materials allows the construction of sample chambers with large access windows, greatly simplifying their design compared to any other probe. The neutron's dipole magnetic moment allows for spin and magnetic field dependent measurements. Therefore, development of ancillary equipment that Canadians need would be another important function of the coordinating hub.

Clearly, quality instrumentation and collaboration as keys to a successful experiment were top of mind in our CINS member survey. For experienced users of neutron facilities, the valuable data is worth the time and monetary expense of planning and traveling abroad, as these issues were of lesser concern. However, hearing from the many occasional users of the Canadian Neutron Beam Centre, a trip abroad is prohibitively expensive and risky on tight research budgets. Without some experience, outcomes of a neutron experiments can be a little uncertain, and limited NSERC research money may be better spent at home. Even the tremendous learning experience for students to travel to a foreign laboratory may not be worth the risk. This leads to a vicious cycle, where the next generation of researchers simply do not consider neutron scattering as part of their research program, and while the rest of the world advances with new neutron sources, Canada is left behind. Thus the CNI believes that serious financial travel support is a necessary component to any partnership with a foreign facility.

Expanding Domestic Capabilities

Through the Canadian Neutron Initiative, Canada aims to continue to be good stewards of neutron beam research infrastructure both domestically and abroad. This means proper utilization of the McMaster Nuclear Reactor by expanding its operation schedule to 24/7 and to full power output, capital investment in beamlines and equipment, and critically, an on-going user program to ensure that the Canadian researcher can use these investments most effectively. For CFI funded projects, 87% of project leaders reported that they had both adequate financial and human resources for the operations of management of the infrastructure, primarily through Federal and Institutional grants [7]. This is not really true of MNR today, whose operational budget is limited to what it can recover through commercial revenues from sources such as isotope production and neutron radiography. It has little-to-no operating funding intended to support research presently.

In return for the envisioned investments through CNI, the MNR neutron beams would be available to all Canadian researchers without additional fees. Overall, only about 60% in total of CFI-funded infrastructure is made available to users outside the host institution [7]. The CFI often finds that for equipment it funded underutilization or oversubscription is very rare. However, if adequately supported and operated as a user facility, the MacSANS beamline after its completion in 2019 is expected to draw many polymer and soft material scientists now currently forced to travel abroad. MacSANS is designed to perform optimized neutron diffraction on nanoscale structure in the range from 1 to 100 nm, and could perform up to 40 experiments a year with an improved operating schedule of the MNR.

The CNI also has a priority to add at least two beamlines for routine diffraction experiments, and make user access easier and more convenient. For example, powder diffraction by X-rays is a routine tool for structural characterization of most newly synthesized crystalline materials. Neutron powder diffraction is as well, with the added benefits of being isotope or magnetic lattice sensitive. For stable samples, the flux of MNR is more than sufficient to collect high resolution data. A reflectometer for thin film measurements is also possible on a different beamline.

Paving the Way for the Future

Major investments in new neutron sources worldwide are required even just to keep pace with the closures of old neutron facilities. Canada should be at the discussion table for investing in new international sources and must consider investing in a new domestic source. Over the next few years, the research community will continue to discuss the questions of how, what kind, and where, establishing itself as a strong constituency in a new research reactor alongside the communities that require isotope production capabilities and in-core testing for nuclear power applications. The focus of the CNI is to preserve and strengthen that community in the absence of a major domestic neutron beam source over the next decade, at least.

Canada has much to learn from experience of Denmark. The DR3 reactor at the Risø National Laboratory was permanently closed in 2000 due to a series of faults with aging infrastructure. This was the last domestic source for neutrons in Denmark, however, the Danish government heeded the needs of the researchers. In the following decade, several instruments were moved to foreign facilities, and the Danish government set up a travel fund so that its community of researchers could continue to collaborate with their European counterparts, and remain on the cutting edge of research.

It wasn't until late 2015 when the European Spallation Source (ESS) project was established by the European Commission as a European Research Infrastructure Consortium. Jointly owned by the governments of Sweden and Denmark, the ESS is currently under construction in Lund, Sweden, an hour by train from Copenhagen. Designed to be the world's most powerful neutron source, the user program for the first few beamlines should be open in 2023 to researchers from Denmark, Sweden, and other financially participating countries. It will have been nearly a quarter century since Danish scientists had direct access to a 'domestic' neutron beam facility, but they continue to use neutrons as a research tool thanks to a government responsive to the needs of its researchers.

In February 2017, King Carl XVI Gustaf of Sweden led a tour of the ESS construction site for the previous Governor General of Canada, David Johnston, and current Canadian Minister of Science, Kirsty Duncan, as part of a four-day Canadian state visit to Sweden. Canadian Nobel Laureate Art McDonald participated in the round table discussion during the February state visit, which focused on cross-disciplinary research as a vital driver for sectors such as life science, clean technology, forestry, and communications technology. McDonald strongly endorses the idea of a financial partnership with Canada and facilities such as the ESS, since `world-class research and innovation require large, national-scale science facilities that are accessible and maintained at the state-of-the-art' [8]. In November 2017, a delegation of CINS members representing quantum materials, engineering, biophysics, and energy research traveled to the ESS to discuss in greater detail possible scientific partnerships. We learned of the plans and needs of this complex facility and fill in details on how Canada can support, and benefit from this powerful laboratory.

Partnerships with world-leading foreign facilities, and expanded use of the MNR, will ultimately bridge the gap to a new Canadian neutron beam laboratory. Hopefully, in the not too distant future, we can reciprocate and bring the world's top researchers to a new neutron source here to Canada.

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