Report on outcomes of Canadian Neutron Initiative working group activities supported by BrightnESS^2

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Canadian Neutron Initiative

CANADIAN NEUTRON INITIATIVE

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SUMMARY

The Canadian Neutron Initiative (CNI) working group is coordinating a pan-Canadian effort to rebuild Canada's capabilities for materials research with neutron beams. Neutron beams are an irreplaceable part of a complete twenty-first century scientific toolkit to address technology challenges in priority areas, such as producing and storing clean energy, growing the economy through advanced manufacturing and clean technologies, and promoting health through biomedical and life sciences.

Because Canadian researchers require access to high-brightness neutron sources, in 2019 the CNI working group partnered with BrightnESS^2, an EU-funded project that promotes collaboration between the European Spallation Source (ESS) and countries both inside and outside Europe. Key activities of the CNI that were supported by the agreement included two major Roundtable meetings and the development of a high-level Canadian national neutron strategy, which details four strategic objectives concerning (1) foreign partnerships, (2) building on Canada's existing domestic capabilities, (3) developing new neutron sources for the long term, and (4) creating a new governance and management framework to implement the activities of the strategy.

The partnership with the ESS through the BrightnESS^2 project has been successful at meeting its objectives. Key outcomes of the activities supported by BrightnESS^2 included general agreement among Canada's neutron beam community regarding the national neutron strategy. A variety of excellent opportunities for partnerships with facilities in the U.S. and Europe have also been identified, as access to such world-class facilities is urgently required to address Canada's neutron beam shortage. The CNI working group has also secured support to create a national coordinating organization, provisionally called "Neutrons Canada," and is now proceeding with its establishment. One of the roles of Neutrons Canada will be to serve as the primary point of contact for foreign neutron facilities to negotiate access agreements.

Until Neutrons Canada is formally established, which is estimated to take place over the next year or two, the CNI working group is interested in continuing the dialogue with the ESS to explore further collaboration opportunities. The ESS, soon to be the world's brightest and most powerful neutron source, will offer attractive scientific capabilities that will not be available at any other facility. To access these capabilities and fully participate in the ESS in the long term, the Canadian neutron

beam community must first establish precedents of collaboration that demonstrate its need to access the world's brightest and most powerful neutron source. Modes of collaboration could include exchanging knowledge through research collaborations and knowledge-sharing events; cooperating on the development of the long-range plan for neutron infrastructure for Canada; conducting experiments granted through the competitions for beam time for non-member countries; and investing in neutron beamline capital projects that leverage access to beam time and to the scientific activities of the ESS.

If and when sufficient interest from the Canadian neutron beam community is demonstrated, Neutrons Canada could advise the Canadian government concerning an application for Observer status in the ESS. Neutrons Canada would also be well positioned to cooperate with other major research facilities in Canada to engage with the Canadian government concerning policy solutions that could better enable Canada to join multi-national science facilities as an equal participant. In time, Canada could even become an Associate Member of the ESS.

CANADIAN AND EUROPEAN CONTEXT FOR THE PARTNERSHIP

Canadian universities are planning for the future of materials research with neutron beams, following the end of a 70-year era of Canadian excellence in this field enabled by major neutron sources (i.e. the NRU reactor) at the government-owned Chalk River Laboratories. Within this context, a Canadian national neutron strategy is emerging. The strategy includes partnering with high-brightness neutron sources in other countries, as well as building on Canada's remaining domestic capabilities (e.g. the medium-flux McMaster Nuclear Reactor). The CNI working group is coordinating this strategic planning and is steering the establishment of a new, pan-Canadian, university-led framework for the stewardship of Canada's capability for research with neutron beams over the long term.

Europe is likewise in a state of planning and implementing a renewal of its neutron beam capabilities. Thirteen European countries have partnered to construct the flagship ESS, which will be the world's brightest neutron source. European nations have also invested in new or upgraded capabilities at other neutron sources, such as the Institut Laue-Langevin, the Heinz Maier-Leibnitz Zentrum, and the ISIS Neutron and Muon Source—all of which are attractive to Canadian researchers. These investments come at a time when older neutron sources are shutting down. Notably, three

sources in Europe closed in 2019, and only nine remain. It is currently expected that only a handful of these will continue to operate into the 2030s.[1] The success of the ESS is thus critical to maintain European leadership in research that relies on neutron beams.

The Canadian need for partnership with high-brightness neutron sources, combined with the European need to ensure the success of the ESS, formed the basis for a cooperative and productive relationship between BrightnESS² and the CNI working group.

PARTNERSHIP WITH THE ESS THROUGH BRIGHTNESS²

BrightnESS² is an EU-funded project that supports the long-term sustainability of the network of neutron sources in Europe, with particular focus on the ESS and its community. One of the objectives of BrightnESS² is to reinforce the ESS as a global research infrastructure and to provide a platform to explore collaboration opportunities between the ESS and countries both inside and outside Europe. Work Package 5 of BrightnESS² is dedicated to international outreach, stakeholder engagement, and the internationalization of the ESS's member base. The project started in January 2019 and will end by June 2022. BrightnESS² builds on the legacy of its predecessor, BrightnESS, which concluded in 2018. The presence of the ESS at the annual meeting of the Canadian Institute for Neutron Scattering (CINS) in 2016, as well as the visit of a Canadian delegation to the ESS in 2017, both took place within the framework of BrightnESS. BrightnESS² builds on these activities to further strengthen the collaboration between the ESS and Canada.

Acting on behalf of the CNI, the Fedoruk Centre entered into a partnership agreement with the ESS under the BrightnESS² project in 2019 in order to (1) exchange knowledge, experience, and information; (2) organize events to support and develop each other's efforts in creating awareness around neutron scattering and research; and (3) explore collaboration opportunities, such as (a) promoting the international aspirations of the CNI and other key Canadian players among relevant

[1] Low Energy Accelerator-driven Neutron Sources. LENS Ad-hoc Working Group CANS. League of European Neutron Sources (LENS) Nov. 2020. https://www.lens-initiative.org/2021/02/03/

decision-makers on the national level; (b) coordinating participation of the ESS and Canadian players in the International Conference on Research Infrastructures (ICRI 2021); and (c) examining prospects for Canada to obtain Observer status in the ESS and for other activities that could support the long-term collaboration between the ESS and Canada.

KEY ACTIVITIES OF THE PARTNERSHIP

The projects identified in the agreement and the related activities to support the above objectives of the partnership are listed in Table 1. Documents are available at http://neutrons.ca.

The Roundtable meeting towards establishing Neutrons Canada, held in January 2020 (Project No. 1), was a gathering of university executives from 16 universities across Canada to discuss the CNI proposal for a new pan-Canadian, university-led framework to manage Canada's infrastructure, international partnerships, projects, and programs for materials research with neutron beams. The proposal focused on the creation of a new entity, provisionally called "Neutrons Canada," that would manage a coherent national program built on domestic and foreign infrastructures. Neutrons Canada was envisioned to be of the scale, complexity, and impact of a Major Research Facility (MRF), as such infrastructure is called in Canadian policy (or a "research infrastructure" in European policy terms[2]). Participants heard from representatives of neutron research infrastructures in Europe, including the ESS, who discussed their facilities' capabilities, best practices in governance, and lessons in managing multi-national research infrastructures. The January 2020 Roundtable meeting resulted in a report on the discussion and consensus of the participants (Output for Project No. 1).

[2] https://www.esfri.eu/glossary

Table 1. Projects, activities, and published documents of the CNI working group supported by BrightnESS[2].

Projects and Activities	Outputs
Project No. 1: Roundtable meeting towards establishing "Neutrons Canada," held in January 2020	"Canadian Leadership in Materials Research with Neutron Beams" (a report on the Neutrons Canada Roundtable)
Project No. 2: Roundtable meeting to shape a Canadian neutron strategy, held in December 2020 Producing an accompanying discussion paper on a national neutron strategy	"Report on Outcomes of the CNI-CIFAR Roundtable on a National Neutron Strategy" "A National Strategy for Materials Research with Neutron Beams" (consultation draft, February 2021) 1-page summaries: • "Towards a National Neutron Strategy" • "Vers une stratégie nationale sur les faisceaux de neutrons"
Project No. 3: Joint participation in the International Conference on Research Infrastructures (ICRI 2021)	The ESS was highlighted in two sessions at ICRI 2021 by former ESS Director General, John Womersley: • Session A2 • Session C1
Project No. 4: Final report	"Report on outcomes of Canadian Neutron Initiative working group activities supported by BrightnESS[2]" (the present document)

The Roundtable meeting in December 2020 (Project No. 2), convened by the CNI working group and CIFAR[3], brought together a cross-section of stakeholders to shape a Canadian national neutron strategy for rebuilding Canadian capacity for materials research with neutron beams. The 88

[3] CIFAR is a Canadian-based global research organization that convenes extraordinary minds to address science and humanity's most important questions. http://www.cifar.ca/

participants included 40 leading scientists from universities and industry; 20 Vice-Presidents of Research and their designates from 13 Canadian universities; representatives of the U15 Group of Canadian Research Universities, government agencies, and leading neutron facilities (including the ESS); and other leaders in Canadian research.

A priority activity for Project No. 2 was to produce an accompanying discussion paper on a national neutron strategy. The resulting discussion paper represents the culmination of five years of strategic thinking and consultations that had been taking place since 2015, when the plan to close Canada's primary neutron source, the NRU reactor at Chalk River Laboratories, was announced. These consultations were conducted with universities across Canada, government agencies, industry, and potential foreign partners, as well as with researchers individually and collectively through the Canadian Institute for Neutron Scattering (CINS). A consultation draft of the national neutron strategy discussion paper, as informed by these preceding consultations, set the stage for conversation at the December 2020 Roundtable meeting, and was subsequently updated to reflect individual contributions and common themes expressed by Roundtable participants.

The final draft of the discussion paper on a national neutron strategy (Output for Project No. 2) presents an extensive exploration of the value of neutron beams to meet Canada's social, environmental, and health challenges, and describes the present and historical context for materials research with neutron beams. It details four strategic objectives concerning (1) foreign partnerships, (2) building on Canada's existing domestic capabilities, (3) developing new neutron sources for Canadian researchers to access for the long term, and (4) creating a new governance and management framework to implement the activities of the strategy. In addition to the national neutron strategy discussion paper, the December 2020 Roundtable meeting also resulted in (1) a public report on the meeting, and (2) one-page summaries of the strategy in both of Canada's official languages (additional Outputs for Project No. 2).

Regarding joint participation in ICRI 2021 (Project No. 3), the Fedoruk Centre, as secretariat to the CNI working group, and the ESS applied their networks to reach out to the ICRI Organizing Committee, aiming to introduce a conference session to highlight neutron research and the internationalization of research infrastructures. The ESS was highlighted by John Womersley, former

Director General of the ESS, in two sessions at ICRI 2021 (Output for Project No. 3): “Developing a Business Case for International Research Infrastructures: The European Spallation Source” (Session A2); and “Broadening Perception of the Impacts of Research Infrastructures: The European Spallation Source” (Session C1). Both the CNI working group and the ESS provided participants in ICRI 2021, raising awareness about neutron science and the internationalization of research infrastructures.

This final report (Project No. 4) summarizes the main outcomes of all activities carried out within the agreement and identifies long-term collaboration opportunities between Canada and the ESS (Output for Project No. 4).

OUTCOMES OF THE PARTNERSHIP

General agreement among the Canadian neutron beam community on the national neutron strategy was a key outcome of the above activities. The community is optimistic about the future of Canadian materials research with neutron beams, as envisioned in the strategy, despite setbacks such as the closure of the NRU reactor. Regarding foreign partnerships, the community perceives a variety of excellent opportunities for partnerships in both the short and long term with facilities in the U.S. and Europe. There is broad agreement that access to foreign neutron facilities is an urgent priority to address the present neutron beam shortage in Canada—and will continue to be essential even after the McMaster Nuclear Reactor is fully optimized as a domestic anchor facility. Indeed, there is agreement that Canada should be a contributor to the global supply of neutron beams. Partnerships offer access to world-leading scientific capabilities and the ability to shape these capabilities according to Canadian needs. They offer highly inspiring educational opportunities for students, as well as opportunities for Canadian industry to benefit from developing cutting-edge technology for neutron sources and instruments.

There is also broad support for the creation of Neutrons Canada, the national coordinating organization envisioned in the strategy. Neutrons Canada will be needed to secure capital and operating funds for major research infrastructure, and also to operate the resulting programs and infrastructure on behalf of the Canadian neutron beam user community. Such a national organization is best placed to create processes and structures for consensus building and long-range planning—

planning that must include the prioritization of foreign partnerships. Neutrons Canada will be needed to serve as the primary point of contact for the foreign neutron facilities interested in partnering with Canada and to negotiate access agreements with those facilities.

The CNI working group is proceeding to steer the establishment of Neutrons Canada, having held the first meeting of Founding Members in January 2022, attended by Vice-Presidents of Research or their designates from 13 universities across Canada. While the CNI working group does not bind Neutrons Canada or its Members, it expects that the establishment of Neutrons Canada will take place over the next year or two, in order for it to assist with major projects, operations, and funding proposals, some of which are already underway—including, most notably, the ramp-up of the neutron beam lab at the McMaster Nuclear Reactor over the next several years. A full description of Neutrons Canada and its context is provided in the Neutrons Canada Prospectus.[4]

FUTURE COLLABORATION OPPORTUNITIES WITH THE ESS

The ESS will offer uniquely powerful scientific capabilities that will be attractive to Canadian research. It will enable *in operando* studies of materials for fuel cells, super capacitors, and batteries, and will allow for characterization of the micro-structures of engineering materials during processing conditions. It will offer the ability to study biological samples that cannot be studied elsewhere, either because they scatter neutrons too weakly or because the dynamics of their biological systems are too quick. It will enable the study of magnetism, atomic structure, and vibrational modes in samples of quantum materials that have so far been too small to study and too difficult to grow.

A challenge for MRFs in Canada is the absence of an established policy mechanism that allows Canada to join multi-national science facilities. Canada is not a member of the ESS or of any other European Research Infrastructure Consortium, or ERIC (a legal status regulated by the EU). For instance, even though Canadian scientists have been involved in the ATLAS experiment at the CERN Large Hadron Collider since the early 1990s, with over a hundred Canadian scientists contributing to

[4] Canadian Neutron Initiative working group. Neutrons Canada Prospectus. November 2021. https://fedorukcentre.ca/resources/neutrons-canada-prospectus---2021-november.pdf

ATLAS today, the Canadian particle physics community has not yet identified a means by which to pay the membership fee for Canada to join CERN. The Canada Foundation for Innovation (CFI) Major Science Initiatives (MSI) Fund, which was created in 2012 to defray operating costs of Canadian MRFs, may provide a means for a Canadian MRF such as Neutrons Canada to cover some costs of operating infrastructure outside of Canada as part of its infrastructure program. However, an investment in the ESS at a level of a one to five percent membership share, for example, would be difficult through this mechanism—and may even be impossible without a record of collaboration on the infrastructure.

Once formally established, Neutrons Canada will be well positioned to cooperate with other MRFs in Canada to engage with the Canadian government concerning policy solutions that could better enable Canada to join multi-national science facilities as an equal participant. The Canadian federal government has been considering how to improve the stewardship of its investments in MRFs following *Canada's Fundamental Science Review* in 2017 [5], which provides a suitable context for such engagements. Further, engagement between the Canadian neutron beam community and the ESS could create influential precedents that inform not only the science and business cases for a future membership in the ESS, but also any associated changes to Canadian policy that would be required to enable it. To that end, possible modes of collaboration between Canada and the ESS are identified below.

1. *Capital investment.* A common means for Canada to partner in research infrastructures abroad is to contribute to capital projects, such as new instruments or upgrades to instruments, through the CFI Innovation Fund (IF). The contribution can be cash or in-kind. For example, the CFI 2020 IF award included $11 million CAD in total contributions to instruments at the Spallation Neutron Source and the NIST Center for Neutron Research in the U.S. In return, a proportionate amount of beam time will be available to Canadian beam time applicants. The CFI 2023 IF competition is currently underway, and the CFI IF fund will hold competitions every two to three years. An application for a future investment in ESS could propose cash and in-kind

[5] Canada's Fundamental Science Review. http://www.sciencereview.ca/eic/site/059.nsf/eng/home

components. For instance, investments in instruments could be accompanied by Canadian postdoctoral associates placed at the ESS to participate in the instrument development—an arrangement that could catalyze the formation of collaborative projects between Canadian and European researchers, which would constitute a natural route for access to beam time. Such capital projects would present opportunities for Canada to help shape and define the ESS's scientific capabilities, ensuring that they are developed in science areas required by Canadian users.

2. *Participation in long-range planning.* The national neutron strategy provides a high-level outline of Canada's requirements to rebuild its capabilities in research using neutron beams. The Canadian neutron beam community has identified the need for a Long-Range Plan (LRP) for neutron beam infrastructure. The neutron LRP would be a specific and realistic plan for the infrastructure investments needed to implement the national neutron strategy. It would identify, and build alignment around, a concrete set of projects, operations, and other fundable activities. Engagement by the ESS in the LRP process could lay essential groundwork toward a future partnership between the ESS and Canada, as major projects in the future—including those that require CFI IF funding—would be identified in the LRP.
3. *Knowledge exchange.* Canadian events, such as those organized by the CNI, Neutrons Canada, and the Canadian Institute for Neutron Scattering, are opportunities to share knowledge with Canadian scientists, raise awareness of the capabilities that the ESS will offer, and foster collaboration. Canadian scientists who collaborate with research teams in ESS member countries will have greater exposure to, and more opportunities to access, the ESS's unique capabilities. There is a growing interest in Canada in accelerator-based neutron sources and time-of-flight instruments, and Canada needs to develop its expertise in these areas. Collaboration with the ESS and with European scientists through the exchange of researchers who work on development projects would be an effective way to share knowledge.
4. *Direct competitive access.* Even those researchers who do not form collaborative teams with European scientists could apply for the small fraction of ESS beam time that will be awarded based on scientific merit to researchers from non-member countries. Expert users from Canada

will be well positioned to compete for this beam time, although it is recognized that the quantity will be limited.

CANADIAN STATUS IN THE ESS

The ESS is structured as a multi-national organization whose Members may be countries and intergovernmental organizations. Legally, the ESS is an ERIC. The status of Canada within the ESS could take one of three forms, outlined below.

1. *Associate Membership.* Associate Membership will generally pertain to non-EU countries. Both Full and Associate Members will contribute to construction (e.g. source and instruments) and operations. All Members will have access to the instruments. Operations contributions will be calculated according to each Member's scientific use of the facility. Associate Membership may provide an opportunity for building an instrument at the ESS, or the ability to join existing instrument teams to contribute to instruments. Associate Members would also benefit from new scientific opportunities that arise from the ESS.
2. *Observer status.* The statutes of the ESS's ERIC allow for a non-member country to join as an Observer. Observers may be countries that are willing to contribute to the ESS, but are not yet in a position to join as Members. Observer status is normally limited to three years, but this may be extended in exceptional cases. As an Observer, Canada could appoint an organization (i.e. Neutrons Canada, as a non-governmental entity with a public service mission) to represent it to the ESS. Neutrons Canada could then attend the ESS Council without voting rights. Canadian researchers could participate in ESS events (e.g. summer schools, workshops, conferences, and training courses) at preferential rates, space permitting.
3. *Ad hoc collaborator*. The ESS can enter into other collaboration agreements with organizations and research communities, subject to approval by the ESS Council.

A reasonable path forward for Canada in its present context is to pursue *ad hoc* collaboration opportunities with the ESS (such as those described in the earlier section "Future Collaboration Opportunities with the ESS") until Canadian researchers demonstrate sufficient interest in using the

ESS's unique capabilities to warrant a more formal arrangement. A notional timeline for such a path could evolve as follows:

- **Laying foundations (2022–2025):** Over the next three to four years, Canadian efforts will focus on (1) securing access to neutrons from foreign facilities that are in full operation; (2) building and upgrading domestic facilities; and (3) establishing Neutrons Canada (as described in the "Outcomes of the Partnership" section)—each of which is necessary to sustain the Canadian neutron beam user community and maximize opportunities to train young researchers. The Canadian community will also develop its LRP for neutron beam infrastructure, which may be complete in 2023, and may pursue subsequent funding opportunities (e.g. the CFI 2025 IF competition). Knowledge exchange activities between Canadian researchers and the ESS could lead to capital investment opportunities at the ESS being identified in the LRP, and to Canadian researchers applying to the direct competitive access mechanism when the ESS user program opens. In parallel, Neutrons Canada could cooperate with other MRFs in Canada to propose policy solutions to enable Canada to join multi-national science facilities.
- ***Ad hoc* collaborator status (2026–2029):** Following three years of cooperation in 'Laying foundations', if ESS is identified as a part of Canada's long-range plan for neutron infrastructure, then an agreement, or set of agreements, could be negotiated between Neutrons Canada and the ESS, most likely as an ad-hoc collaboration. As ESS will be operating during this period, such agreements should include specific access to ESS beam time, which in turn would begin to establish a scientific basis for Canada's future prospects as an Associate Member of ESS. An ad-hoc agreement between the two organizations could include ESS beam time in exchange for some Canadian capital investment, or beam time allocated to Canadian researchers as part of a programmed scientific or technical collaboration.
- **Application for Observer or Associate Member status (2030 and beyond):** If warranted by the demonstrated scientific demand, and if enabled by Canada's policy framework, Neutrons Canada could advise the Canadian government concerning an application to the ESS for Observer status, and subsequently for Associate Member status.

CONCLUSION

The partnership with the ESS through the BrightnESS[2] project has been successful at meeting its objectives. The CNI working group has secured support for a national neutron strategy and for the creation of a national coordinating organization, Neutrons Canada. Neutrons Canada is expected to represent Canada to foreign neutron sources. Until Neutrons Canada is formally established, which is estimated to take place over the next year or two, the CNI working group is interested in continuing the dialogue with the ESS to explore further collaboration opportunities.

Modes of collaboration between Canada and the ESS could include exchanging knowledge through research collaborations and knowledge-sharing events; cooperating on the development of the long-range plan for neutron infrastructure for Canada; conducting experiments granted through the competitions for beam time for non-member countries; and investing in neutron beamline capital projects that leverage access to beam time and to the scientific activities of the ESS—each of which would lay the foundations for Canada to hold Observer status or even become an Associate Member in the ESS in 2030 or beyond.