The Canadian Neutron Beam Centre: 1985 to the Present Day

by John Root and Daniel Banks

From Bertram Brockhouse's pioneering 1950s experiments, Canada's neutron beam capabilities grew organically into the Neutron and Solid State Physics (NSSP) branch of AECL's Physics Division. In the 60s and 70s, university researchers had access by collaborating with AECL scientists. Researchers from McMaster and Guelph established instruments at beams E3 and D3, respectively, but both were decommissioned by the mid-1980s. The high scientific impact of the NSSP branch during these decades is seen in the 2016 Nobel Prize in Physics, awarded to Duncan Haldane and two other American theorists, because AECL's Bill Buyers used neutron scattering to confirm the Haldane gap's existence in 1985, leading to acceptance of the future laureates' theories, which in turn opened the field of topological materials.

The construction of DUALSPEC (1985-1992), at a capital cost of $4M, marked a turning point for general user access to neutron beams at Chalk River. DUALSPEC, including the C5 Polarized Beam Triple-Axis Spectrometer and the C2 High Resolution Powder Diffractometer, was funded 50:50 by AECL and NSERC via McMaster University. Malcolm Collins (McMaster) led 11 university scientists from McMaster, Toronto, Guelph, Laurentian, Queen's and Waterloo on the proposal [1]. Because the two beams are only three feet apart in height, AECL designed a single monochromator shield that would allow both to operate independently.

Neutron scattering researchers established the Canadian Institute for Neutron Scattering (CINS) in 1986 to maximize access to DUALSPEC, evaluate beam time proposals for scientific merit, and represent their collective interests. DUALSPEC's original applicants were joined by others from the University of New Brunswick, St. Francis Xavier, Simon Fraser, and Dalhousie in an NSERC infrastructure grant for $55K/yr, paid via McMaster and matched by AECL, for DUALSPEC commissioning and operation starting in 1991. Throughout 1992, DUALSPEC supported 46 users from 9 Canadian universities and 12 foreign institutions, a good beginning for a user-access program [1].

Summary

A program perspective on Canada's primary neutron scattering laboratory as a scientific user facility, and on parallel work to support consideration of replacing the National Research Universal (NRU) reactor.

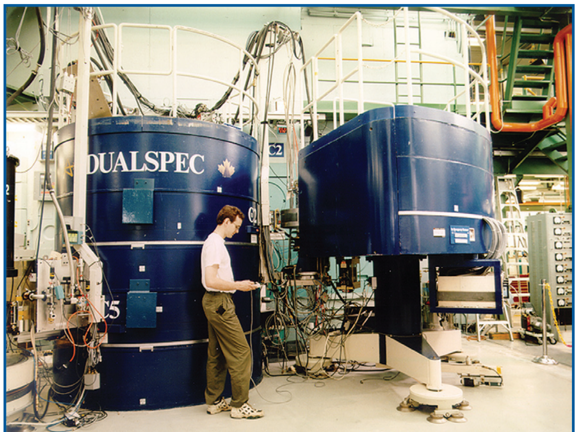

Fig. 1 AECL scientist Ian Swainson adjusting the scattering angle of the C2 powder diffractometer, on the upper beam of DUALSPEC to the right, with the C5 triple-axis spectrometer positioned on the lower beam, to the left.

Although the total grant of $110K/yr did not cover DUALSPEC's full costs, AECL increasingly welcomed user access to four of its other spectrometers: three triple-axis spectrometers at E3, L3, and N5, and a prototype low-angle scattering instrument at T3.

While academic access was ramping up, the AECL NSSP branch was developing applications for industry. In 1983, Tom Holden demonstrated stress mapping of intact components of nuclear power reactors on the L3 beamline and established a commercial service, Applied Neutron Diffraction for Industry (ANDI). After the Space Shuttle Challenger disaster in January 1986, ANDI was selected over comparable USA capabilities to examine an as-manufactured section of booster rocket casing. Neutron diffraction showed that the stress distribution was acceptable, pointing the failure investigation to look elsewhere [2]. ANDI became the go-to service for failure analyses for high-profile accidents, such as the Space Shuttle Columbia

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in 2003 and the 2005 train derailment at Lake Wabamun in Alberta, which spilled 800,000 litres of oil. ANDI ran successfully for over 20 years, providing proprietary data to enhance safety and reliability or optimize processes in energy and manufacturing sectors such as air, automotive, rail, and marine transportation, metal production, and oil & gas.

In the early 1990s, the future was bright at AECL's newly renamed Neutron and Condensed-Matter Sciences (NCMS) branch, with the success of ANDI and the growing user-access program. The user community rallied behind a concept for NRU's successor, the Irradiation Research Facility (IRF). This hopeful outlook was validated when Brockhouse shared the 1994 Nobel Prize in Physics with Clifford Shull of Oak Ridge National Lab (USA) for their pioneering contributions to neutron scattering.

Yet clouds of uncertainty began to gather. The McMaster Nuclear Reactor (MNR), which had beamlines for powder diffraction and a Small-Angle Neutron Scattering (SANS), was planned to shut down in 1996 (MNR still operates today). When its SANS detector failed in 1994, there was no funding to continue, and both beamlines were eventually decommissioned. NSERC declined a $3M proposal in 1995 for a new SANS instrument at the vacated D3 beam line at the NRU reactor, to be funded jointly with AECL, as was DUALSPEC [3]. Reportedly, NSERC's decision reflected an understanding that NRU would close in 1998. Meanwhile, the federal government was reducing programs to balance its budget. In mid-1995, it became apparent that AECL's basic research programs were at risk in the federal program review. The neutron user community was mobilized and about 100 support letters for the NCMS branch were secured from eminent Canadian and foreign scientists, directors of foreign neutron laboratories, and representatives of industry.

In spring 1996, AECL's budget was cut deeply, and decisions were made to eliminate many activities in physics, health, and environmental sciences, including the TASCC facility, a leading particle accelerator for heavy-ion nuclear physics. Though AECL continued operating the NRU reactor at ~$20M/yr in direct costs to support its reactor business and generate medical isotopes, it would not continue the expense of $2M/yr to operate the NCMS branch, but allowed a year to find other arrangements. Senior officials at Natural Resources Canada (NRCan, responsible for nuclear matters) and Industry Canada (responsible for science and economic development) agreed that the NCMS's capability should be retained, but it was still in danger of falling between jurisdictional cracks.

Ironically, in early 1997 while NCMS staff awaited news of their fate since they were deemed non-essential for AECL's nuclear business, they were called upon for stress measurements for New Brunswick Power, which was bleeding about $400K per day because of an unplanned shutdown of the Point Lepreau Nuclear Generating Station. A heavy-water leak had been found in one of hundreds of feeder pipes running between the reactor core and the steam generators. About 16 hours after receiving an archived feeder, NCMS staff established that the stress was a worst-case scenario that resulted from the manufacture of the bend. Understanding the problem was key to providing assurance to the regulator, which allowed the reactor to restart. Resolution of this emergency led to a line of research on feeders that saved nuclear plant operations hundreds of millions of dollars over the following years [4].

A deal was struck some weeks later and in April, the NCMS branch was transferred to the National Research Council of Canada (NRC), then under President Arthur Carty, as the Neutron Program for Materials Research (NPMR). Some staff were laid off because of a smaller budget: $1.5M/yr for three years primarily from NRCan with contributions from NSERC and NRC, after which NRC might decide to assume ongoing responsibility for the program. The $110K/yr funding for DUALSPEC operation continued separately.

As NRC now had a direct interest in neutrons, NRC and AECL cooperated on the "Canadian Neutron Facility" (CNF), a new concept for NRU's replacement for nuclear materials testing, neutron scattering, and limited isotope production (excluding Mo-99, which was to be made by the MAPLE reactors under construction). The CNF was approved in principle by a cabinet committee in 1999, and thus was ready to be funded, if funds were found. However, AECL withdrew its support in 2000 to focus resources on developing an Advanced CANDU reactor.

Well supported by NRC and the neutron scattering community, the NPMR emerged strongly from the crisis of the mid-90s. It soon began to grow again, attracting $1M/yr from NSERC's Major Facilities Access (MFA) program in 2001 toward maintaining the entire facility, not just DUALSPEC, in a state of readiness for user access. As CINS president, Bruce Gaulin (McMaster) was the principal applicant to the MFA program, later remodelled as the Major Resource Support (MRS) program, and the funds were paid via McMaster. Excluding the T3 beamline, which had become obsolete, NPMR's five active beamlines averaged 30 users per beamline per year. An international peer review in 2004 reported that only three facilities in world had more users per beamline (ILL, ISIS, and NCNR), observing that "an extraordinarily high fraction (~90%) of the beam time is available to users" compared to 50-66% elsewhere, and the 13% of beam time used by industry as a commercial service "is an extraordinarily high number matched by no other neutron scattering facility." The NPMR "has had productivity per dollar, per instrument, and per staff scientist that competes well with the very top international neutron facilities" concluding that "NPMR is a world-class program run on a shoestring" [5]. Yet the uncertain future about the NRU reactor's lifetime, and a replacement facility, was a challenge, and investment in new equipment or upgrades were not keeping pace with world-leading facilities, for the most part.

In 2004, a CFI award was granted to Western University to build a $2.4M neutron reflectometer at the D3 beam. David Shoesmith and Jamie Noël led the proposal, supported by 12 universities. NRC's Zin Tun provided scientific leadership for the design and D3 opened for user access in 2007. Also in 2004, NSERC's contribution to operate the NPMR was renewed under the leadership of Dominic Ryan (McGill), who served as CINS President until 2014.

Renamed the Canadian Neutron Beam Centre (CNBC) in 2005, the lab reached its peak around 2008, with 6 beamlines highly subscribed by a community of over 700 frequent and occasional research participants of all types: scientists, engineers, and students, from universities, industry, and government labs, from Canada and around the world. The ANDI service had generated about $6M of fee-for-service revenue from over 200 projects. The CNBC had delivered over 1000 beam allocations to users since 2001, and NSERC increased its MRS grant for five years, starting in 2007. The CNBC's $4M/yr operations had achieved a funding balance of 60% from NRC for baseline operations, 30% from NSERC to maintain facilities in a state of readiness for user access, and 10% from commercial services and other R&D income. Numerous beamline upgrades were distinguishing the CNBC in stress scanning, powder diffraction, and polarized triple-axis spectroscopy.

Prospects for a successor to NRU were again looking up, as discussions began anew in 2006 between Industry Canada (IC), Natural Resources Canada (NRCan), AECL, and NRC. These agencies reflected intertwined issues under federal review: Chalk River's role as a national nuclear lab, the structure of AECL, a national nuclear policy, Mo-99 supply, and a framework for investing in major facilities like TRIUMF, the Canadian Light Source, and perhaps a replacement for NRU. The Canadian Neutron Centre (CNC) concept was a flexible, versatile machine that could do whatever Canada might need from a research reactor, including the full range of isotope production, which distinguished the CNC from the earlier CNF, because the MAPLE reactor project was in trouble at the time. CINS published the requirements of neutron beam users in the CNC in 2007 [6]. The Canadian Nuclear Society made a parallel document outlining requirements for reactor-based nuclear science and technology [7], while the Canadian Nuclear Association, which represents companies, helped NRCan to study Canada's needs for nuclear S&T broadly.

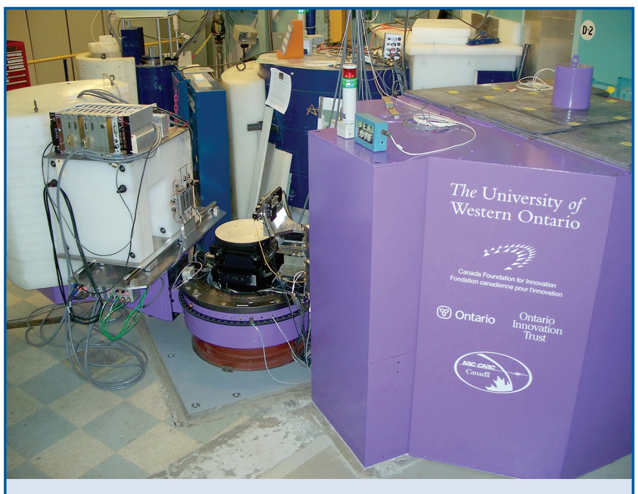

Fig. 2 The D3 reflectometer at the time of its opening in 2007, labelled with logos of the funding partners: the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the Ontario Innovation Trust and the National Research Council. Western University was then known as The University of Western Ontario.

The CNC proposal could not retain government attention due to distracting issues such as the divestiture of AECL's commercial business lines to a new company Candu Energy (2009-2011), global shortages of Mo-99 caused by NRU maintenance shutdowns (2007, 2009-2010), and a $1.6B lawsuit from Nordion over cancelling the MAPLE reactors (2008-2013). The government postponed considering the CNC pending AECL's restructuring, and the NRC lost interest after its own restructuring to become more responsive to industry began in 2010. In March 2010, the federal government sent a clear signal to industry and the Ontario government, which owns most of Canada's nuclear power stations, that it was not interested in taking on a new research reactor by itself, calling for "appropriate sharing of costs among the many users and beneficiaries of such a facility" [8]. Although the Saskatchewan government offered $200M in 2009 toward building a dual-purpose reactor for isotopes and neutron beams, that proposal left most of the cost with the federal partner and did not meet the nuclear industry's needs.

Phase two of AECL restructuring began with a February 2012 call for expressions of interest in AECL's Laboratories, which warned "should there be limited or insufficient response, support may be reduced or ended for some or all of the Laboratories' activities beyond radioactive waste and decommissioning obligations." Although CINS and other groups of researchers made submissions, NRCan reportedly didn't recognize a strong constituency for the neutron beam mission, because senior university leaders were not strongly engaged. In February 2013, NRCan announced that the labs would retain a research mission focused on industry and government needs, and that government would assess the business case "for an industry-driven nuclear innovation agenda."

That decision was just in time to preserve the CNBC. Federal austerity measures following the global 2008 recession led to NSERC's moratorium on its MRS program and significant cuts at NRC. The CNBC was at the end of a year of "wind-down" MRS funds when NRC decided to cut CNBC's funding, effective April 1, 2013. However, the CNBC had a role to play for AECL, demonstrating return on investment in NRU and retaining capability that might comprise part of a future nuclear innovation agenda. Therefore, AECL agreed to take responsibility for operating the CNBC, with the NRC staff seconded to AECL, and assets remaining property of NRC.

From 2009 to 2013, the uncertainty about NRU's future, hiring freezes within NRC, the lack of neutrons for 15-months beginning in 2009, and MRS funding losses presented severe challenges. The CNBC did not recover from losses in soft materials expertise or in the ANDI service's momentum. Yet in other areas, the CNBC bounced back under AECL and its successor organization, Canadian Nuclear Laboratories (CNL). Research participants grew to over 800 over the last five years, compared with over 700 for the five years ending in 2008. Although proprietary research for industry dropped off, the total proportion of beam time for industry remained the same due to a large increase in public domain research involving prominent companies such as GM, Ford, Nemak, Yamaha, StandardAero, Rolls Royce and Schlumberger.

In February 2015, NRU's final closure was announced as March 2018, ironically providing more certainty than in the past 20 years, and enabling productive final years. Now that the NRU reactor is closed, a final year remains in the agreements between NRC, AECL and CNL for continued operation of the CNBC, to wrap up the scientific outcomes of the final neutron beam experiments, and organize future placements for staff and equipment.

This is not the end of Canadian neutron scattering. An enduring truth is that the unique ways neutrons interact with materials enables neutron beams to reveal knowledge that may be difficult or impossible to acquire otherwise. Canadians will still need neutron beams to train and work at the leading edges of science and technology. Companies will still need them to develop new products, to optimize their processes, or to enhance reliability.

The neutron beam community must continue without a domestic high-flux source and without the leadership of the federal agencies that provided stewardship of Canada's neutron-beam capabilities until now. The next article describes the Canadian Neutron Initiative, which seeks to unify all Canadian stakeholders behind a new framework – a new university-led framework that partners with world- leading foreign facilities, fully exploits the medium-flux McMaster Nuclear Reactor, and establishes a trusted voice in the coming deliberations [9] about access to neutrons for the long term.

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