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ACTIVITY REPORT 2011 - 2013

CANADIAN NEUTRON BEAM CENTRE

Probing Materials for Science and Industry

Canadian Neutron Beam Centre Activity Report to the Canadian Institute for Neutron Scattering for 2011, 2012 and 2013

A series of technical reports submitted by our community of international users concerning their experiments at the Canadian Neutron Beam Centre complements this summary report of activities. The technical reports are available online and are presented in the language in which they were submitted: http://www.cins.ca/expreports.html.

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PROBING MATERIALS FOR SCIENCE AND INDUSTRY

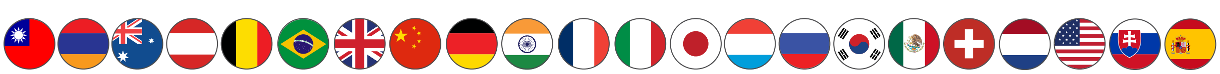
The Canadian Neutron Beam Centre (CNBC) at AECL enables hundreds of clients, from industry and academia, to apply uniquely powerful neutron instruments and methods to advance their programs of materials research and development.

Our industry clients come from many industry sectors: Aerospace ➢ Automotive ➢ Biotechnology ➢ Electronics ➢ Metal Production
Mining ➢ Nuclear Energy ➢ Oil and Gas ➢ Other Energy ➢ R&D Services

Our Canadian government clients are: Atomic Energy Canada Limited ➢ Canadian Nuclear Safety Commission
Natural Resources Canada ➢ Defense Research and Development Canada
National Research Council ➢ Transportation Safety Board

1 University of British Columbia
2 Simon Fraser University
3 University of Calgary
4 University of Alberta
5 University of Saskatchewan
6 Brandon University
7 University of Manitoba
8 University of Winnipeg
9 Lakehead University
10 University of Windsor
11 Western University
12 University of Waterloo
13 University of Guelph
14 McMaster University
15 Ryerson University
16 University of Toronto
17 Brock University
18 Queen's University
19 Royal Military College
20 Carleton University
21 University of Ottawa
22 Concordia University
23 Université de Montréal
24 École Polytechnique de Montréal
25 McGill University
26 Université Laval
27 École de technologie supérieure
28 Université INRS
29 Université du Québec à Trois-Rivières
30 Université de Sherbrooke
31 Mount Allison University
32 University of PEI
33 Dalhousie University
34 Saint Francis Xavier University
35 Memorial University

The specialised facilities and expertise of the CNBC support business innovation and serve as resources for Canadians to train and work at the leading edge of science and technology. 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 typically include more than 700 individuals from over 60 departments in about 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. The CNBC typically provides more than 85% of its neutron beam time to the user community.



HOW A NEUTRON BEAM FACILITY WORKS

Researchers come from all over Canada and the world to probe materials with neutron beams to find solutions to challenges in health, industry, and science. From the initial inquires into the feasibility of an experiment to the final interpretation of results, CNBC scientists and technical staff provide support to our users to ensure that this national resource is accessible to any user.

Overview of an experiment

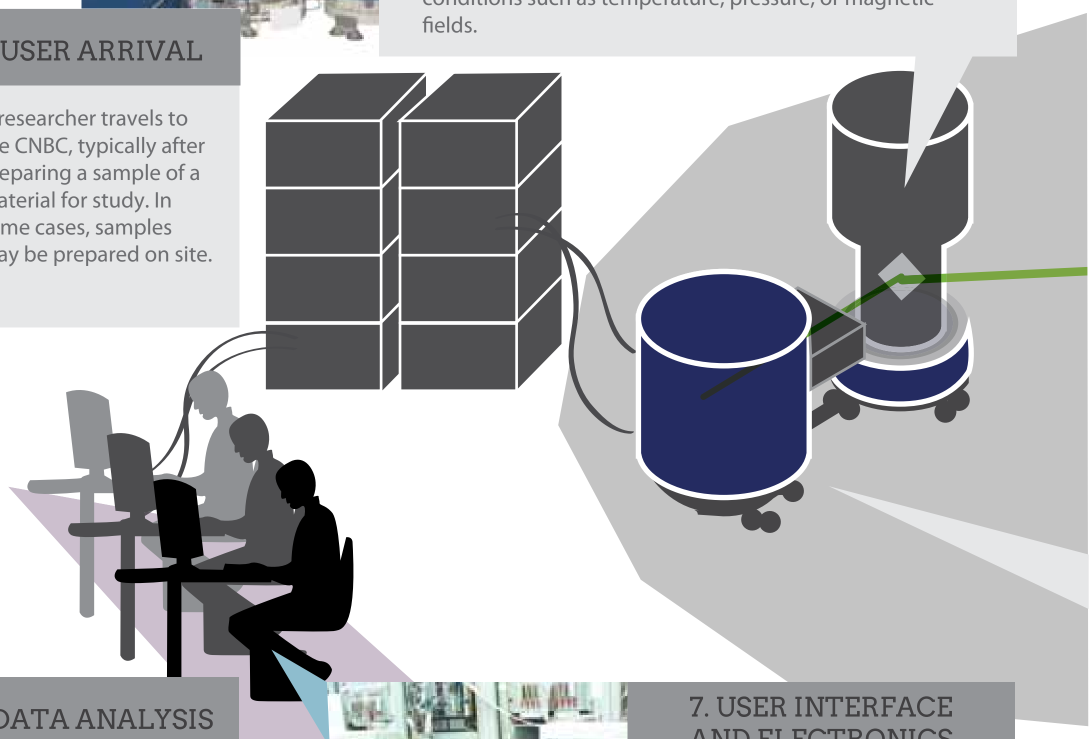
As neutrons pass through a material, the material changes the properties of the beam, such as the direction, energy, or magnetic polarization. By detecting these changes, researchers can deduce certain properties of the material such as atomic structure or stress.

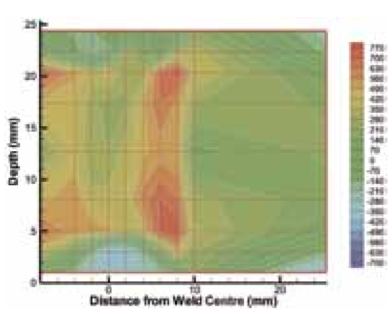
5. SAMPLE MATERIAL

A sample material is placed in the emerging beam. As the neutrons pass through, the material changes the properties of the beam, such as the direction, energy, and magnetic polarization. Typically, the beam is scattered in many directions. A chamber around the material controls conditions such as temperature, pressure, or magnetic fields.

1. USER ARRIVAL

A researcher travels to the CNBC, typically after preparing a sample of a material for study. In some cases, samples may be prepared on site.



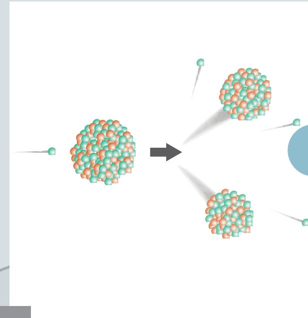


8. DATA ANALYSIS

Data analysis typically continues after a user travels back to their home institution. CNBC scientists follow up with the users to assist with the analysis and interpretation of results.

7. USER INTERFACE AND ELECTRONICS

A specialized electronic system controls each portion of the beam line and collects the experimental data. Workstations provide the user interface to control the experiment and perform preliminary data analysis.



2. NEUTRON PRODUCTION

Neutrons are tiny particles that reside in atoms. When uranium atoms are split in the reactor core, neutrons are released in every direction with a large spectrum of energies.

3. BEAM PRODUCTION

Several tubes through the reactor wall allow some neutrons to exit in the shape of a beam. Excess neutrons are absorbed by the reactor wall.

4. BEAM PREPARATION

A crystalline material diffracts the beam, that is, it divides the beam according to the energies of the neutrons. A channel is positioned to allow only neutrons of a certain desired energy to proceed to the sample material. The remaining neutrons are absorbed in the wall of the large cylinder encasing the crystal.

6. NEUTRON DETECTION

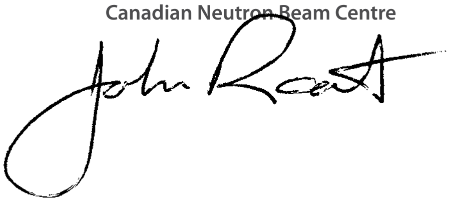
A mobile detector system determines the intensity of the scattered beam in various directions.

THREE YEARS OF SOLID PERFORMANCE MIDST CHALLENGES

DIRECTOR'S MESSAGE

The CNBC has enjoyed three solid years of providing neutron beams to researchers since the National Research Universal (NRU) reactor at Chalk River returned to service on August 17, 2010.

John Root, Director,
Canadian Neutron Beam Centre



This report provides statistics about our service to users and highlights examples of current research and impacts arising from this work. The CNBC's solid performance has continued despite uncertainties in funding and governance during this period.

In April 2012, the Natural Sciences and Engineering Research Council (NSERC) notified the Canadian Institute for Neutron Scattering (CINS) that it was placing a moratorium on its Major Resource Support program. Yet, because CINS's application to provide support to the CNBC was "highly meritorious", NSERC provided one year of ramp-down funding to assist with the transition.

Thanks to this transitional funding, there was time to find an alternative arrangement without impacting service to our users. The National Research Council (NRC) negotiated a two-year

STATISTICS FOR 2011 TO 2013

Over the three years from 2011 to 2013, the CNBC delivered 3926 beam days. This beam time was divided among 336 experiments for 219 projects.

92% of this beam time was delivered to user projects for Canadian universities, foreign institutions, government laboratories or industry.

The remaining 8% of beam time was used by the CNBC to develop innovative neutron beam methods and new applications, or for maintenance and testing purposes.

The CNBC retained strong engagement with the user community, with 551 individuals participating in research depending on access to the CNBC. These included 62 individuals from Canadian industry and Canadian government labs, as well as 181 individuals from 70 university departments spread among 30 Canadian universities in seven provinces (Alberta, British Columbia, Manitoba, Nova Scotia, Ontario, Quebec and Saskatchewan).

The CNBC remained highly leveraged with foreign collaborations. Of the 551 research participants, 308 were from 104 foreign institutions in 20 countries (Australia, Austria, Belgium, Brazil, China, France, Germany, India, Italy, Japan, Luxembourg, the Netherlands, Russia, Slovakia, South Korea, Spain, Switzerland, Taiwan, the United Kingdom and the United States).

agreement to transfer the operations and funding of the CNBC to Atomic Energy of Canada Limited (AECL), effective April 1, 2013. The CNBC continues to be owned by NRC. The CNBC continues to provide access to neutron beams as before, as this function is aligned with AECL's program to provide access to federal nuclear innovation infrastructure and expertise to the Canadian science and technology community, so that they can advance their innovation agendas.

The CNBC represents one of the three missions of AECL's NRU reactor, which is:

- Canada's only major neutron source, supplying neutrons for the CNBC;
- Canada's only major materials testing reactor, supporting nuclear energy research and development; and
- an important production facility in the global supply of medical radioisotopes.

AECL's corporate plans indicate an intention to relicense the reactor for an additional five years and continue its missions, except for the production of the isotope Mo-99.

Our overarching issue and concern remains the long-term prospect for Canada's source of neutrons.

The long-term future for the NRU reactor and a possible new research reactor for Canada await government decisions on whether to invest in an industry-driven, nuclear innovation agenda.

In the meantime, the CNBC will rejuvenate and expand its competencies in neutron scattering research, by building new neutron beam facilities, developing applications of neutron scattering to new areas of science and technology, and providing support for Canada's lively and growing neutron-scattering community.

Top view of the National Research Universal (NRU) reactor, which supplies neutrons to the CNBC for materials research.

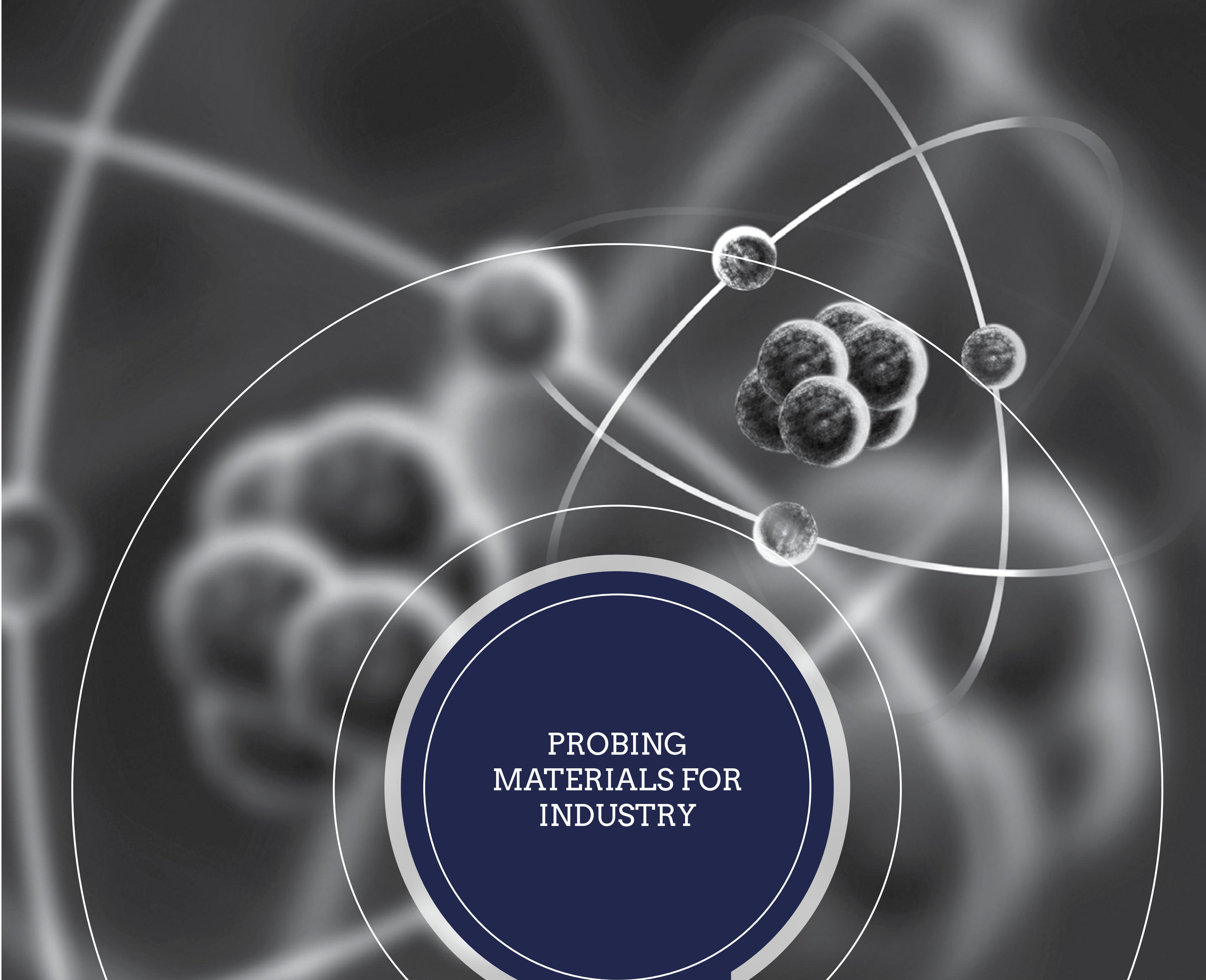
CNBC User Statistics

Community Function	Indicator	2008	2009[1]	2010[1]	2011	2012	2013
Access	Number of users.[2]	161	96	87	162	137	159
Canadian Access	Users from Canadian institutions.	75%	72%	76%	61%	68%	66%
Participation	Number of research participants.[3]	258	235	229	246	285	297
Leverage of International Collaboration	Percentage of research participants from foreign institutions.	39%	43%	48%	48%	54%	49%
Canadian Academic Participation	Number of Canadian universities represented by research participants.	18	19	18	24	21	17
Academic Participation across Disciplines	Number of Canadian university departments represented by research participants.	37	32	32	36	35	36
Training of Highly Qualified People	Number of students and post-docs who visited the CNBC to conduct research.	44	22	20	36	34	27

CNBC Facility Statistics

Statistic	Indicator	2008	2009[1]	2010[1]	2011	2012	2013
Beamline Capacity	Reactor operating days multiplied by six beamlines.	1578	606	594	1476	1440	1428
Beamline Efficiency	Percentage of available beam days occupied by projects.	88%	90%	92%	85%	90%	96%
External Usage	Percentage of beam time occupied by user-led projects.	86%	83%	93%	91%	95%	90%
Average Experiment Duration	Average beam days per allocation.	10.5	9.0	11.9	11.5	12.4	11.3
Project Demand[4]	New proposals received per year.	57	40	34	52	56	62

[1] The NRU reactor was shut down from May 14, 2009 to August 17, 2010.
[2] A user during a given year is defined as an individual who either visited the CNBC during the year to conduct an experiment, or is a co-proposer of an experiment that ran during the year.
[3] A research participant during a given year is an individual who was a user during the year, or is a co-author of a paper resulting from work carried out at the CNBC that was published during the year. This is a standardised measure for North American neutron facilities.
[4] About 50% of projects require more than one access to the beamlines. The typical number of projects allocated beam time in a year is between 80 and 100.



PROBING MATERIALS FOR INDUSTRY

Neutrons have some unique properties that make them an ideal probe for industrial research:

They penetrate deeply into dense materials such as metals and alloys.

They interact with nuclei of atoms, enabling the precise measurement of stresses in materials and components.

They can probe material samples that are held under realistic conditions of pressure, temperature and stress.

They are non-destructive; they do not damage the specimen under examination.

Left: Electrochemical production of sodium chlorate.

Right: Canada's paper manufacturing industry contributes $8.8 billion per year to GDP.

Commercialising Energy-saving Technology for Paper Manufacturers

MEEIR Technologie Inc. is seeking to commercialise energy-saving technology following research that accessed the CNBC.

MEEIR Technologie Inc. has been partnering with IREQ to commercialise these electrodes. IREQ has invested over $1 million in research and development to further develop them.

Canada's sodium chlorate industry is the largest in the world, with revenues of over $350 million per year. Sodium chlorate is exported to the United States and is used by Canada's $8.8-billion-per-year paper manufacturing industry to bleach its paper products. These industries are challenged by the strong Canadian dollar, declining demand for newsprint, and by the rising prices of energy.

The cost of electricity represents more than 45% of the production cost of sodium chlorate, which is made by an electrochemical process. One way to combat rising electricity prices is to conserve energy by designing more efficient production methods. Specifically, Hydro-Québec's research institute, IREQ, has conducted research over the past decade in developing new cathodes that could save substantial amounts of power for the industry, estimated at $6 million annually in Quebec alone.

Researchers from IREQ accessed the CNBC to understand their new cathode material. Specifically, they used the neutron beamlines to precisely locate atomic positions in a nanocrystalline alloy, Ti_2RuFeO_x. Better understanding of this material has led to modifications of the chemical composition of the alloy to enhance its performance.

Since April 2007, MEEIR Technologie Inc. has been partnering with IREQ to commercialise these electrodes. IREQ has invested over $1 million in research and development to further develop them. Manufacturing facilities for producing industry-sized prototype cathodes have been established. MEEIR Technologie Inc. has been working with the major sodium chlorate producers in Canada to run prototype production cells, to demonstrate improved performance compared to production cells currently in use. MEEIR has now completed a few years of demo operations in production environments—an essential step in demonstrating the value of this improved technology to the market place.

Our industrial clients are enjoying the rewards of yesterday's research while pursuing tomorrow's gains today.

Boosting Reliability for Natural Gas Extraction

Schlumberger, a multinational oil and gas company, recently conducted research with the CNBC aimed at improving reliability and reducing costs of resource extraction. This research builds on a successful project with Schlumberger performed a decade ago.

The long-term competitiveness of Canada's oil and gas industry depends in part on technologies that make development of unconventional oil and gas resources more economical. One rapidly growing method for unconventional natural gas is hydraulic fracturing (known as "fracking"), where high-pressure solution is pumped into older gas wells to crack rocks, to allow gas to flow more easily. The area of the pump that receives the greatest wear over its lifetime is the fluid end. Replacing fluid ends in many wells is a multi-million-dollar expense for the global fracking industry.

Reducing these costs by increasing the reliability of fluid ends is a development goal of Schlumberger, an innovative multi- national firm providing oilfield services in Canada and around the world. To strengthen fluid ends for service in the high-pressure environment of a well pump, compressive stress, that is, "good stress" in this case, is purposely created in the material during manufacturing. In 2001, collaboration between Schlumberger, Queen's University and the CNBC verified that the good stress remains in the fluid ends even after being put into service.

Fluid ends are used in both oil and gas wells to assist in extraction.

A fluid end on the beamline.

Building on this previous success, Schlumberger returned to the CNBC in 2012 to investigate whether this good stress would also persist in a newly-designed fluid end intended to increase reliability. Schlumberger will use the residual stress measurements taken at the CNBC to validate their finite- element analysis model that predicts the amount of stress in the material. Being able to confirm that the model is in agreement with measurements is a first for this new fluid end. Due to the success of this research project, Schlumberger expects its collaboration with CNBC to pay many dividends in the long and short term.

Stress data from the CNBC are helping Schlumberger develop more reliable fluid ends. Replacing fluid ends is a multi-million dollar expense for the fracking industry.

Studying the performance of aluminium in this prototype engine block for Nemak Inc.

Enabling Lighter, Better Car Engines

Taking care of our environment, improving the fuel efficiency of cars, and promoting competitiveness of Canadian industry are Canadian priorities.

Stress data from the CNBC led to a further project to develop manufacturing methods to optimise performance of light-weight alloys for car engines.

For Canadian manufacturers that export vehicles and parts to remain competitive, they must be able to meet regulatory changes abroad. Beginning with 2017 models, the United States is requiring a 50% improvement over today's passenger vehicles by 2025. Innovations that optimise performance and prolong the life of light-weight engines are needed to meet these standards. Manufacturing techniques for casting and forming light metals, such as aluminium, must be better understood and redesigned.

This is the goal of an AUTO21-funded research team comprising two automotive companies (Nemak Inc. and General Motors), three universities (Ryerson, UBC and Waterloo), and two government labs (Canmet Materials and the CNBC). The team seeks to understand the small-scale effects of each stage of the manufacturing cycle on the metal, to guide predictions for improving the resulting material, and then to confirm the predictions by experiments. Stress measurements at CNBC over the past two years produced very clear information about the effectiveness of stress relief in engine manufacturing, such as heat treatment.

"Residual stress measurements through neutron diffraction experiments at CNBC enabled an enhanced and more lucid understanding of the stress distribution and microstructural aspects of our research on engine blocks," explains Professor Ravindran. "The partnership between Ryerson University, Nemak Canada and CNBC has resulted in outcomes far exceeding our initial targets."

"This is a vital contribution to the overall project that complements studies of metal microstructure, mechanical testing and computer modeling by our AUTO21 research team," says Dr. Robert MacKay, casting and heat treatment specialist from Nemak Inc.

The knowledge gained has led to a second phase of the project over the next two years; that is, to develop advanced casting technologies and heat treatment processes to optimise the performance of lightweight alloys that may ultimately be used in various automotive powertrain components, such as cylinder heads, engine blocks, and transmission cases. For this second phase of the project, the AUTO21 team is leveraging contributions from the industry valued at $240,000 and from government labs valued at $380,000.

http://dx.doi.org/10.1007/s11661-012-1340-0

pursuing tomorrow's gains today …

... enjoying the rewards of research today.

Adding Value to Steel Manufacturing

Canadian manufacturers have been hit hard by the rise of the Canadian dollar over the past decade, which drives up the cost of exports. Steel manufacturers in Canada who export products have been forced to restructure and re-engineer their businesses models to remain competitive.

For example, Ivaco Rolling Mills (IRM), one of three groups of companies that compose IVACO, is expanding its steel plant at L'Orignal, Ontario. IRM operates one of the largest rod mills in North America and it offers the largest range of rod diameters in North America. The $80-million expansion project consists of upgrades that will allow the company to increase its production of steel billets by 225,000 tons annually, and to produce new steel grades for higher-quality products and applications. The availability of these higher-quality grades of steel billets will allow the rolling mill to increase production, further penetrate and expand its market share and enter new markets.

Dr. Nicholas Nickoletopoulos, General Manager at Ifastgroupe and Sivaco Wire Group (IVACO), attributes part of the IVACO success in recent years to research and development conducted a decade ago with the CNBC.

"That research helped us build a stronger scientific reputation that was needed to compete in the world market," says Dr. Nickoletopoulos. "Having detailed, fundamental knowledge of the strain and stress states in our customer's deformed steel parts allowed us to add value to our products and gain an edge over our competitors."

"Having detailed, fundamental knowledge of the strain and stress states in our customer's deformed steel parts allowed us to add value to our products and gain an edge over our competitors."

A key to making more reliable fasteners such as bolts and screws involves understanding how to minimise or divert strain concentrations in the metal during each manufacturing step. That is why Dr. Nickoletopoulos tackled the difficult problem of modelling strain and stress states when he was a graduate student at McGill University and an engineer with IVACO. In parallel, he accessed neutron beams at the CNBC to measure the actual residual stresses in the steel at each manufacturing step. The experimental data validated his calculations and gave assurance that his finite-element method model could be used to predict the stresses in fastener products made from IVACO's steel.

Today, IVACO still employs his model when upgrading its product mix, and is reaping the benefits of increased competitiveness that have come from materials research enabled by the CNBC.

IVACO is expanding today, partly because of research using the CNBC that enabled it to add value to its products.

IVACO facilities in L'Orignal, Ontario.

CNBC staff load a special chamber containing the highly radioactive steel sample onto the neutron beamline for stress measurements.

Managing the Aging of Nuclear Power Stations in Japan

Nuclear nations have billions of dollars invested in each of their nuclear power reactors. Operating these stations for many years is essential to realising their return on investment by generating large amounts of emissions-free electricity. The longer they run, the greater the economic and environmental benefit.

Japan's 50 nuclear reactors plan for a 60-year operating life. Seventeen of these reactors are older than 30 years and are undergoing maintenance activities to reduce the impacts of aging. The Japanese nuclear operators and vendors cooperated to fund a project by the Japan Nuclear Energy Safety Organization (JNES) to improve methods of assessing and responding to the aging process, meaning, the degradation over time of metallic materials in the reactor core due to high radiation fields.

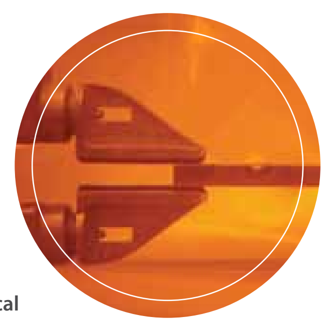
As part of the JNES effort, Nippon Nuclear Fuel Development Co. (NFD) collaborated with the CNBC over several years to study one of six kinds of degradation; specifically, cracking caused by a combination of stress, corrosion and radiation, known as "irradiation-induced stress-corrosion cracking" (IASCC).

Stress data obtained at the CNBC contributed to a guide that is used by nuclear operators in Japan to inform decisions about expensive replacements of in-core components that may be susceptible to cracking.

The CNBC measured stresses in various welded samples of stainless steels that are used to construct the core of Japan's reactors and that are susceptible to cracking over the lifetime of the reactor. The samples were then irradiated in the Japan Materials Testing Reactor for up to 100 days, to accumulate damage from fast-neutron bombardment of the steel, thus simulating the conditions of nuclear power reactors. As a result, the samples became highly radioactive, which required the CNBC to develop a special container to hold them safely on the neutron beamline, to enable measurements of the stress distributions near the welding lines. The CNBC is the only neutron beam facility in the world with this capability. The results of this research conducted from 2000 to 2007 showed that the fast-neutron radiation helps to relax the stresses in the welded samples, thus reducing one factor that could contribute to cracking with age.

The knowledge gained from stress measurements at CNBC was submitted to JNES and used, along with data from crack growth rate tests and theoretical modelling of stress and crack growth, to draft a guide for nuclear operators in 2009 to evaluate whether components in the reactor core are susceptible to cracking. In 2010, JNES submitted its evaluation guide, along with broader research on technologies for evaluating IASCC, to a committee of the Atomic Energy Society of Japan responsible for developing and standardising IASCC evaluation practices. While the guide itself remains tentative because it is expected to continue evolving as new knowledge emerges, nuclear operators currently use the guide to make more informed decisions about when to perform expensive replacement operations.

http://dx.doi.org/10.1016/j.jnucmat.2010.11.023



Radioactive welded steel sample held by mechanical manipulator arm inside hot cell at CRL.

enjoying the rewards of research today ...

... pursuing tomorrow's gains today.

Enhancing Safety of Oil and Gas Pipelines

North American society today depends critically on reliable sources of fuel for energy production, including a steady flow of oil and gas to the market through pipelines.

In Canada alone, pipelines transport enough fuel per day to drive one million cars for 4,000 km. Canadian pipelines increase public safety by removing the equivalent of 4,200 rail cars from our rail lines or 15,000 tanker trucks from our roads every day.

Despite being the safest, most reliable and most cost-effective means to transport oil and gas, when a pipeline failure does occur, it can be damaging to the environment and to the public's assurance of its safety and security. Pipeline owners prevent failures by using the best scientific methods available to interpret inspection data and inform decisions about, for example, whether to replace a small section of pipeline, which may cost over a hundred thousand dollars.

To solve challenging problems like this, the global pipeline industry pools resources through the Pipeline Research Council International (PRCI), which spends over $10 million per year on research, adding to research funds from government sources such as the U.S. Department of Transportation (DOT) or Natural Resources Canada.

Prof. Lynann Clapham at Queen's University and researchers from GdF Suez are collaborating to access the CNBC to help interpret pipeline inspection data from a technique called Magnetic flux leakage (MFL). Their research, funded by PRCI and U.S. DOT, seeks to develop a library that maps MFL data to specific kinds of defects and conditions of stress around the defect—factors which influence the likelihood of failure.

Magnetic flux leakage is sensitive to the loss of metal from corrosion or mechanical damage, which could be caused by a backhoe digging in the wrong place, for example. Thus, GdF Suez produced dents and gouges in full-sized, pressurised sections of pipe, mimicking the damage caused by a backhoe. Prof. Clapham's research group mapped the stress around these gouges at the CNBC, and is comparing them to computer stress models and experimental measurements of the MFL signal. The group aims to find correlations that can be used to determine if an MFL inspection signal in the field was produced by mechanical damage, and to estimate the level of risk represented by the damage. That data will be useful to the industry as scientific input into decision-making about how to manage affected pipelines.

Stress data obtained at the CNBC will be useful to the industry in making hundred-thousand-dollar decisions about how to manage pipelines that have sustained mechanical damage, for example, as a result of a backhoe digging in the wrong place.

GdF Suez lab simulates dents produced by a backhoe.

A 0.5-m section of large-diameter pipe with a gouge nearly 0.4 m in length.

Victoria-class submarine of the Royal Canadian Navy.

PROBING MATERIALS FOR GOVERNMENT

Canadian government clients are enjoying the rewards of research using the CNBC in the areas of national defence and public safety. Three projects focused on reducing maintenance costs and extending the life of aging fleets have led to beneficial exchanges of knowledge and expertise with our allies. Another project has led to improved regulation of the rail industry to prevent accidents.

Qualifying a new repair method

In 2007, Defence Research and Development Canada (DRDC) accessed the CNBC for a project focused on reducing ship maintenance costs by qualifying a new repair method—"friction stir processing (FSP)"—for components that are difficult or expensive to remove from the ship, such as propellers. Many ships in western navies use propellers made of nickel-aluminium-bronze. DRDC researchers studied the effects of FSP on the mechanical and corrosion properties of this material, while a series of experiments over two years at CNBC measured stress and texture. The collective results provided assurance that FSP and its effects on nickel-aluminium-bronze were sufficiently understood to use FSP for propeller repair. The research team, including representatives of both DRDC and CNBC, was subsequently recognised with a 2008 International Achievement Award by the Technical Cooperation Program (TTCP).

As a result of this research, Canada is revising its specifications and protocols to incorporate the FSP method for propeller repairs. The U. S. Navy has already adopted FSP and expects to save $400,000 per year in propeller repair costs, and these savings may be just the tip of the iceberg. For example, through continued development of FSP, the U.S. Navy seeks to save as much as $1.8 million per year in construction costs of high-speed, light-weight ships.

A rare opportunity in structural assessment

The pressure hull of a submarine has to be carefully maintained because it is critical to crew safety, boat performance and life-cycle costs to the taxpayer. The ability to extend the life of a fleet of subs by even a few years could provide major cost savings for Canada's navy. Extending the design life of a sub requires a complex engineering analysis, which relies on obtaining a detailed understanding of the material state of the hull.

In 2007, the CNBC helped DRDC to take advantage of a rare opportunity to generate knowledge that will be used in the life-extension analysis of Canada's fleet of Victoria-class submarines. During the recent half-life refit of one of these submarines, a small section of pressure hull was replaced. The extracted plate happened to contain a length of original weld from its manufacture in the United Kingdom. Data on weld stresses locked through the metal thickness will be a valuable component of life extension structural assessments. Since these data would impossible to obtain with other means—or without such a rare hull sample—DRDC took advantage of this opportunity to fully characterise the residual stress profile of this type of weld using depth-penetrating neutron beams.

While DRDC expects to make full use of the stress data in the future when determining long-term hull fitness for service, these data are of immediate interest to our allies who have submarines further along in their life cycles, and are addressing some residual stress issues now.

To date, the Department of National Defence has shared these data with two of our allies who requested the data via the TTCP and other forums. The data have also been used as Canada's contribution to an international study with the Australian Defence Science and Technology Organisation. In return, Canada is privy to our allies' experiences in other areas of common and more immediate interest, particularly in the rapidly changing realm of non-destructive examination. These arrangements allow Canada and its allies to get the best value for our submarine maintenance budgets.

Fighting corrosion

As another aspect of life extension, DRDC is studying means to address corrosion on pressure hulls. Over time, corrosion eats away at the pressure hull, gradually thinning it in spots. Overlay welding is one of the few methods suitable to restore this lost material without resorting to the more expensive alternative of replacing an entire section of the hull plating or scantlings.

In 2009, DRDC accessed the CNBC in an effort to define the maximum size of the corroded area over which weld overlays could be used effectively. Sections of hull plates with different sizes of overlaid areas were examined to measure the residual stress distribution deep inside the plates as a result of the weld overlays. The data were then used by DRDC to successfully validate two different finite-element approaches that simulate the effect of welding on the properties of the hull plates, demonstrating the value of both the data and the models.

Because of this success, DRDC is now in closer research collaboration with the U.K., to develop standards for weld repairs in submarine hulls. The United Kingdom is benefitting from access to unique experimental data, while Canada is benefitting from using the U.K.'s alternative submarine hull repair procedures.

Improving Public Safety through Rail Accident Investigation

Forty-three cars of a 140-car freight train derailed along the north shore of Lake Wabamun, west of Edmonton, Alberta, in 2005, rupturing twelve cars and spilling oil along the shore and into the lake. The spill affected the local environment for both human residents and wildlife.

Suspect pieces of track recovered from the area were sent to the Transportation Safety Board (TSB) for metallurgical analysis. Because neutron diffraction is the only method for non-destructive mapping of stresses inside large components, the TSB approached the CNBC to explore whether residual stresses might be linked to fractures in the rails. The experiments, conducted in 2006, established that the residual stress field is perturbed near features called 'shells', which are thought to be the precursors of fractures.

The TSB report on the derailment in 2007 noted the findings of the CNBC that "residual stress may play a role in shell formation," and "in-service loading could be altering the as-fabricated stress state," and concluded, "rail failure, therefore, may be a combination of initial residual stresses, service-induced stress, and in-service loads". A more extensive research program would be required to understand the contributions of each of these factors to rail reliability.

A fracture in rail recovered near Lake Wabamun, Alberta, after the derailment.

Nonetheless, it is clear that residual stresses are one factor affecting how long a rail may be used before so-called "fatigue defects", such as shells, weaken its strength—a point known as the "fatigue limit". Thus, the TSB recommended that Transport Canada (TC) establish standards requiring that rails approaching their fatigue limit be replaced. TC accepted the recommendation and reviewed its Track Safety Rules for minimum frequency of ultrasonic rail testing as a primary way to detect fatigue defects. In February 2011, the TSB deemed the response to its recommendation to be fully satisfactory, noting that the railroad operators now greatly exceed the minimum requirements for inspection frequencies on most main track.

The stress data from the CNBC contributed to the investigation report that led to updated regulations for inspection frequency of rail tracks.

Regarding the cooperation of the CNBC with the TSB, Dan Holbrook, Manager of TSB Western Regional Operations confirmed that, "The commitment of CNBC to apply its world-class scientific tools to help us understand the underlying reasons for some rail failures, is good evidence of their vision to put science to work for Canada."

PROBING MATERIALS FOR SCIENCE

Canadian universities and foreign collaborators enjoy access to the CNBC to enable graduate students to perform hands-on experiments that help us understand how materials work and how they can be used, be they materials found in our bodies, materials with exotic properties such as superconductors, or materials with immediate industrial applications. The students gain essential skills for science and technology careers, while others can build on the resulting foundation of knowledge.

Studying the Functions of Bio-Molecules in Cellular Membranes

Before you can fix your car, you need to understand how it works. Similarly, understanding how your body works is fundamental to delivering better health care.

Your body is a complex system, with thousands of molecules in every cell performing different functions. In many cases, we still do not how they perform those functions, because they reside in or interact with cell membranes, an environment which is problematic to study with many common scientific techniques.

Professor Harroun of Brock University and his students use neutron beams to study these molecules, because neutron beams are effective yet gentle probes of delicate samples that require carefully controlled environments.

One such molecule is Vitamin E. Vitamin E is the only essential nutrient for which no one knows why it is essential, information that may be useful in optimising vitamin supplements. Vitamin E is also difficult to study in clinical trials because the effects of vitamin E only become apparent over long time scales.

Yet, using neutrons at the CNBC, the team was able to pin-point the location of vitamin E's anti-oxidant activity at the interface of a model membrance with its aqueous environment. More significantly, their results point the direction toward more promising lines of research to unravel the mystery. They concluded that a significant body of research on vitamin E, that is, its oxidation kinetics and its products, needs to be revisited by taking into consideration the physical properties of the model membrane.

A second example of a molecule whose function is difficult to study without neutrons because it resides in membranes is a small protein called "KL4". KL4 has been clinically proven to relieve respiratory distress syndrome in premature babies. Respiratory distress syndrome makes it difficult for affected babies to breathe and is a leading cause of death of babies up to one month old in the developed world. While it is known that KL4 helps to improve the exchange of oxygen with carbon dioxide in the lungs, it is not known how the protein does so. The team used neutron beams to study KL4 in the hope that understanding how it works will lead to more effective treatments for lung problems. The neutron beam experiments revealed the orientation of the KL4 alpha helix in a membrane chosen to mimic the conditions of lung surfactant studies.

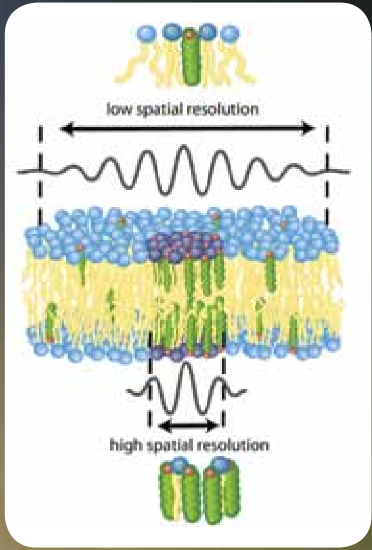
Direct Experimental Evidence of Rafts in a Fluid Lipid Membrane

To explain a wide range of cellular functions, many researchers propose the existence of so-called 'rafts' in the cell membrane, which can be described loosely as tiny islands of order floating in oceans of less-orderly lipids. It is believed that these rafts are induced by cholesterol, and cholesterol is known to play very important roles in determining the structure of the membrane. Observing and characterising these rafts is urgent fundamental knowledge that is needed to advance our understanding and direct future research, but doing so has eluded many researchers until now.

Professor Maikel Rheinstädter of McMaster University and his students made the first direct experimental observations of rafts in a fluid lipid membrane consisting of a binary lipid-cholesterol mixture, and are the first to observe the lipid structure within the rafts. Prof. Rheinstädter used the neutron beams at the CNBC to reveal details of the order in the membrane, suggesting a picture of the membrane as a liquid with small structures, including highly dynamic rafts.

Prof. Rheinstädter used a special variation of neutron diffraction to conduct this experiment. The size of the cholesterol domains within a disordered membrane are so small that the domains cannot be observed in a typical X-ray or neutron diffraction experiment. In a typical powder diffraction experiment, the size of the grains in the powder may be just smaller than what the eye can see but are large enough to effectively scatter probes such as X-rays or neutrons. The lipid rafts are much smaller in volume. A key factor that defines what is too small is the coherence length of the beam. By reducing the coherence length of the neutron beam down to the scale of the nanometer-sized rafts, Prof. Rheinstädter was able overcome these issues and study smaller patches of membrane.

http://dx.doi.org/10.1371/journal.pone.0066162



"My award is 100% connected to the CNBC, not only because all my publications were enabled by access to the neutron beamlines, but because neutron beams allow me to study potentially high-impact problems in biology."

A third example of a difficult-to-study molecule is an anti-microbial agent, known as "chlorhexidine," that is commonly used in personal hygiene products, such as soaps, contact lens solutions, and mouthwashes. Chlorhexidine disrupts bacterial membranes to kill the bacteria. Prof. Harroun's research team is using the CNBC to test ideas about how the molecule works, as they move towards a patentable, membrane-based drug delivery system.

The fundamental importance of this research was recently recognised by NSERC when it awarded a 2012 Vanier Canada Graduate Scholarship to Drew Marquardt, who has been heavily involved in these three research projects. The Vanier scholarships are prestigious awards that aim to attract and retain the world's top-tier doctoral students.

"My award is 100% connected to the CNBC," said Drew, "not only because all my publications were enabled by access to the neutron beamlines, but also because neutron beams allow me to study potentially high-impact problems in biology."

"CNBC has enabled me to study the functions of several key molecules in biology, including vitamin E, cholesterol, a small protein that treats lung problems, and an anti-bacterial agent. What all these have in common is that they perform their functions in cell membranes, an environment which is problematic for many other scientific techniques."

http://dx.doi.org/10.1021/ja312665r

Drew Marquardt sets up his experiment on the N5 beamline. Drew is studying the role of biomolecules such as vitamin E, KL4 and chlorhexidine in membranes at Brock University.

Understanding How Metals Degrade

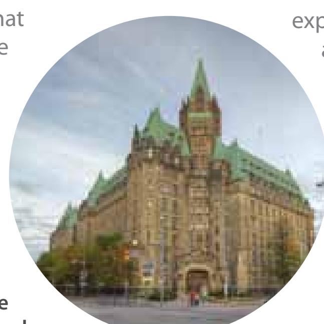
Demonstrating safe, long-term means of storing used nuclear fuel will increase assurance of nuclear safety and security. Understanding and avoiding cracking in the pressure tubes in the core of a nuclear reactor is important to their economic, safe and reliable operation. What both of these areas have in common is the need to study how metals degrade, and specifically, the role of thin films of material that grow on metals.

The exceedingly thin films on many metal surfaces have allowed us to construct a metal-dependent society, comprising items ranging from automobiles to buildings to biomedical implants and beyond. One beautiful and familiar example of such a protective layer can be seen in the green patina that colours the copper roofs of the Parliament of Canada buildings.

Without the protective layer, all of our structural metals would be unstable when directly exposed to air or water. Protective oxide films only nanometers thick often form spontaneously on the surface of a metal, providing a barrier between the metal and its environment and slowing or stopping degradation processes such as corrosion.

Because of the importance of thin oxide films to the performance and longevity of metallic structures, Dr. Jamie Noël from Western University has been collaborating with Dr. Zin Tun from the CNBC to develop and use combined electrochemical and neutron reflectometry techniques to help determine fine details of the nature of oxide layers on metals. Neutron reflectometry allows one to determine the structure and composition of surface layers on a subnanometre scale, by measuring how well neutrons reflect from a material's surface, which acts like a mirror. The union of electrochemistry with neutron reflectometry allows measurements to be made of materials and interfacial properties that are unobtainable by any other means, while they are functioning and exposed to the environment in which they would normally reside.

Successful experiments in used nuclear fuel storage and in reactor pressure tube cracking are just a few examples of the research for which



A green protective layer naturally colours the copper roofs of the Confederation Building and protects the copper beneath it. Photo courtesy of Public Works and Government Services Canada.

Dr. Noël has accessed the CNBC since its neutron reflectometer was commissioned in 2007. He has studied oxide film growth on titanium alloys to help understand their corrosion resistance, which is critical for their possible use to fabricate containers for permanent safe disposal of spent nuclear fuel. He has also probed the conditions under which hydrogen atoms can penetrate the oxide film on zirconium alloys, information that is vital to understanding and avoiding hydrogen-induced cracking in the pressure tubes in the core of a nuclear reactor.

http://dx.doi.org/10.1149/2.020309jes

Doing the Impossible: Neutron Scattering on Gadolinium Compounds

Neutron beams are powerful tools for studying a great range of materials, from biological to industrial, to materials of fundamental interest for physicists. Yet there is a class of materials that many researchers often consider impossible to study with neutron diffraction because they contain elements that absorb neutrons strongly rather than scatter them.

Prof. Dominic Ryan of McGill University has accessed the CNBC to do the impossible, and as a result, has built up a large network of international collaborators from the United States and Europe to investigate materials that have applications in data storage and magnetic cooling and that contain these neutron-absorbing elements.

Gadolinium has the highest tendency to absorb neutrons of all the elements: nearly ten times higher than samarium, which is the second highest, and about 10,000 times higher than metals like iron and copper, which are commonly examined with neutron diffraction. Yet, Prof. Ryan worked with CNBC staff to develop a means to conduct powder neutron diffraction on silicon-doped gadolinium-germanium alloys like $Gd_5Si_2Ge_2$, which has a very large giant magnetocaloric effect. In magnetocaloric materials, the temperature can be greatly changed by controlling a magnetic field around it, a property that can be used for efficient refrigeration.

While other researchers had discovered complex magnetic and structural ordering in these alloys, a full investigation was stymied by an inability to use neutron diffraction to solve the structures. Prof. Ryan overcame the difficulties by developing a low background, flat-plate sample holder, spreading a very thin layer of the powdered alloy over the plate to use the full area of the neutron beam, and collecting data for long periods. The experiments proved that the impossible could be done and solved key aspects of the magnetic and structural ordering of these alloys. These experiments have been extended to several other materials, including new iron-based, high-temperature superconductors and $GdCo_{12-x}Fe_xB_6$, which showed that alternative methods previously used to characterise these materials indirectly gave inaccurate results.

Researchers around the world, who previously believed they could not use neutron beams to study their highly absorbing materials, now call Prof. Ryan, who can get it done using the CNBC.

http://dx.doi.org/10.1088/0953-8984/25/31/316001

Precise Measurements in Superconductors

Someday you may travel to work on a train that levitates above its track. Impossible? Not with the almost magical properties of superconductors, which can generate strong magnetic fields and conduct electricity perfectly without losing any energy. Scientists worldwide are studying superconductors, to understand what causes these unusual effects and to design superconductors that will exhibit these effects under increasingly practical conditions.

Representing a team of researchers in the United States, Belgium and Switzerland, Dr. Vladimir Kozhevnikov accessed the CNBC to perform first-of-a-kind measurements on these exotic materials. Superconductors completely expel external magnetic fields, which is a key to levitation. More precisely, the magnetic field decreases extremely rapidly, that is, over a distance of nanometres, from the surface into the superconducting material. Measuring exactly how rapidly, however, has proved to be extremely challenging and Dr. Kozhevnikov came to the CNBC after these measurements were attempted at a number of other neutron facilities around the world without success.

At the CNBC, Dr. Kozhevnikov successfully measured the in-depth distribution of the magnetic field just below the surface of three superconductors at near-absolute zero temperatures, which allowed his team to determine key parameters that were not yet known precisely for any superconductor, and thereby test competing theories to explain the interplay between magnetism and superconductivity.

In addition to advancing international research, this experiment was also an occasion for science education and outreach. Dr. Kozhevnikov brought four of his undergraduate students from Tulsa Community College to the CNBC to participate in the experiment and learn first-hand about the role that large scientific user facilities play in enabling research for a broad range of science and technology.

"The people I met at the CNBC were very friendly. They were willing and able to explain the answers to my questions and had the patience to expound upon the topics I did not fully understand," commented Michael Jensen, one of the visiting students.

http://dx.doi.org/10.1103/PhysRevB.87.104508

Paving the Way for Future Technology with New Iron-Based Superconductors

A key discovery could disrupt technologies for computing, medical imaging and dissipation-free power transmission lines as we know them today. CNBC's unique expertise and scientific tools are enabling Canadian and international researchers to make an impact at the cutting edge of condensed matter physics and superconductivity.

Superconductivity is a phenomenon where materials conduct electricity with no loss of energy.

Currently, superconductivity occurs only at very cold temperatures. While conventional superconductors lose their electrical resistance at about -240 °C, so-called "high-temperature superconductors" containing copper exhibit this exotic property at temperatures as "hot" as -108 °C.

Dr. Vladimir Kozhevnikov (right) and students at the D3 beamline.

High-temperature superconductors based on iron were discovered only four years ago. These new superconductors are being intensely studied around the world not only because we need to understand the cause of their superconductivity, but because they are stronger candidates for commercial applications due to greater mechanical strength and capacity to conduct electricity than the only previously-known, high-temperature superconductors, which are based on copper.

Prof. Stephen Wilson's research team from Boston College used one of CNBC's six beamlines to explore the relation between magnetic and structural properties of a crystal of $BaFe_2As_2$, and found surprising changes when they compressed the crystal on the beamline using a clamp.

"Our result offers insight into the magnetic and structural phase transitions in iron-based superconductors" said Prof. Wilson. Slightly compressing the crystal caused unexpectedly large effects on both the alignment of the atoms and the magnetic order. The strain allows magnetic domains to exist at higher temperatures, which may indicate a link between magnetism and superconductivity in these materials.

"Neutron scattering has been an invaluable experimental tool in studying these exotic superconductors," Prof. Wilson said. "It enables scientists to simultaneously explore structural and magnetic properties under different physical conditions not possible to be studied by other techniques. Neutron scattering facilities such as the CNBC are vital to such studies."

Being able to conduct electricity at higher temperatures without losing energy may be a future outcome of fundamental studies on superconductors. One day, you may see savings on your electricity bill because all the electricity is conserved in superconducting power lines between a generating plant and your home. Or, the computer on your desk or in your palm may be much more powerful than today, because the speed of computer processors today is limited by the heat produced from their electrical resistance. Or, medical diagnostics that require the strong magnetic fields produced using superconductors may become more efficient, precise and accessible.

Prof. Wilson's research team conducted experiments at the CNBC and at Oak Ridge National Laboratory on the parent compound ($BaFe_2As_2$) of a new class of superconductors. $BaFe_2As_2$ is called the parent compound because it becomes superconducting when holes, electrons or pressure are introduced into the system.

http://dx.doi.org/10.1103/PhysRevB.87.184511

Advances in Hydrogen Storage Materials

If we want to stop using carbon dioxide-emitting fossil fuels in our cars, an environmentally-friendly alternative may be to use hydrogen as a fuel, because it only produces water and energy when it is "burned," that is, when it is combined with oxygen. To build hydrogen-based vehicles, we need materials that store and release hydrogen efficiently so that it can be burned in a vehicle engine.

Neutron beams are effective probes for studying materials that are candidates for storing hydrogen, because they can detect hydrogen within metals. Prof. David Mitlin and his research group from the University of Alberta use neutron reflectometry at the CNBC to examine thin films of these materials under realistic conditions.

One candidate material for hydrogen storage is magnesium because it has a very high storage capacity for hydrogen (7.6 wt.%), but it is limited by its slow response in accepting and releasing the hydrogen. The slow response is due in part to a build-up of magnesium hydride at the surface, which blocks further movement of the hydrogen in and out of the magnesium film.

Recently, Prof. Mitlin observed much faster responses when a combination of other metals was added (chromium and vanadium), and then accessed the CNBC to understand the improvement. The results showed that the addition of chromium and vanadium had the effect of preventing the blocking layer of magnesium hydride from forming and allowing the hydrogen to move much faster throughout the magnesium.

The elucidation of the underlying mechanism led to an examination of the effect of adding other metals like chromium and iron together to the magnesium. This alloy turned out to be another promising hydrogen storage system, in which the blocking layer is prevented in a manner similar to the magnesium-chromium-vanadium system.

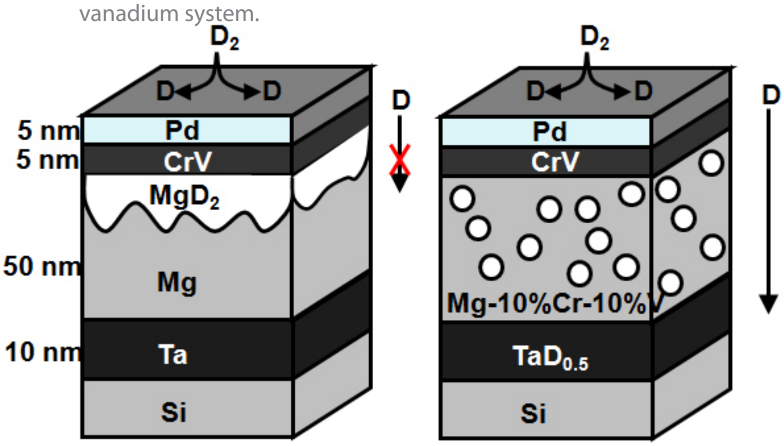


Illustration of hydride formation (in the form of deuterium, D) in thin films of magnesium in which a blocking layer forms (left), and of magnesium-chromium-vanadium in which the hydrogen moves more freely (right).

http://dx.doi.org/10.1016/j.ijhydene.2011.06.014

Research for Nuclear Energy Serendipitously Finds Molecular "Ball on a Spring"

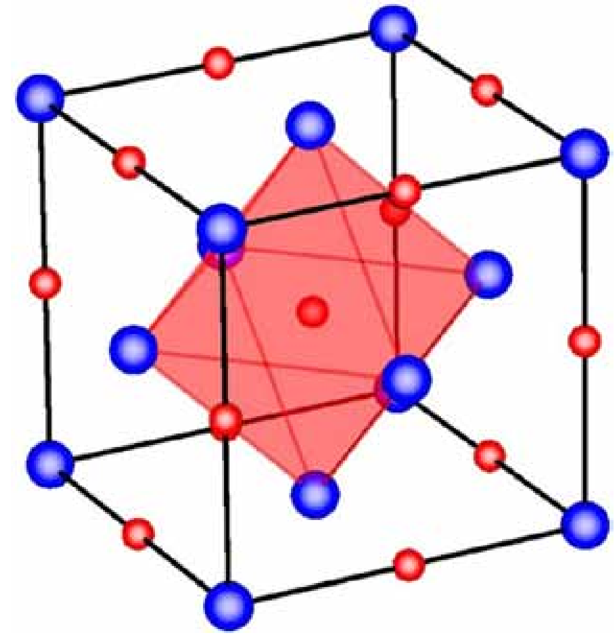
Working with a team of researchers from Oak Ridge National Laboratory, Bill Buyers, a guest researcher at the CNBC, found a nearly ideal example of a molecular "ball on a spring," a theoretical model studied by university physics students everywhere. The model has been useful to illustrate fundamental concepts, but no one had expected to find a real system in nature that matched the model with extreme precision.

The team examined a crystal of uranium nitride, in which nitrogen atoms are trapped inside an octahedral-shaped cage of uranium atoms. Because the uranium atoms are so much heavier, they act like immovable objects to which the lighter nitrogen atoms are tethered.

The team was using neutron scattering to study magnetism in this material, in part because it is being considered as a fuel for more advanced nuclear power reactors; therefore, its properties needed to be fully understood.

The neutron data produced a series of distinct and evenly spaced oscillations that reflected the vibrational modes of the system. The researchers were astonished to realise that the oscillations matched the modes expected for a single-atom, isotropic quantum harmonic oscillator, which is one of the fundamental, exactly solvable problems in quantum mechanics.

This surprising result has practical implications for the nuclear industry, because these oscillations must be accounted for in computer simulations of nuclear power reactors that would use uranium nitride as a fuel.



Nitrogen atoms (red) caged by much larger uranium atoms (blue) behave like a ball on a spring.

http://dx.doi.org/10.1038/ncomms2117

Understanding Stress in Ship Hulls to Enhance Reliability

Eliminating failures of ship hulls is a goal of several North American defence agencies that collaborate on research through the Ship Structures Committee, which aims to lower maintenance costs and enhance the reliability of naval vessels. Because stresses in hull materials may lead to fractures, Professor Sreekanta Das of the University of Windsor collaborated with DRDC to better understand stresses in welded ship hull material.

Sara Kenno, a Ph.D. student studying under Prof. Das, used the CNBC's neutron stress scanner to map the stresses deep inside twelve plates that replicate the welded and stiffened panels in a ship's hull. These plates exhibited three different spacings for L-shaped stiffeners, which are beams welded onto the inside of the hull to add strength. Knowledge of the stress distributions produced by various welding patterns or methods will help to predict how well a hull will resist fractures.

http://dx.doi.org/10.1520/MPC20130007

"My time spent with the world class scientists at CNBC has been invaluable toward completing my Master's and Ph.D. research," says Sara. "I developed research and deductive reasoning skills useful in any research project, in addition to experience using specialised neutron diffraction techniques."

Building More Reliable Models of Materials

The United States spends tens of billions of dollars each year in the construction of ships for defense. It is no wonder, then, that the U.S. Office of Naval Research (ONR) funds basic research programs that may one day stretch defense dollars further. Professor Paul Dawson of Cornell University, who has received ONR funding for about 20 years, aims to create a scientific model that could serve as a foundation for the future design of materials that last longer, perform better, and increase safety margins. Improved alloys, for example, could enhance the ability of ship hulls to withstand pressure or last longer, thereby reducing maintenance costs.

Currently used models sometimes fail to predict a material's behaviour under stress, because they neglect the properties of microscopic grains in the material. Engineers are frequently forced to compensate for this uncertainty by conservatively overbuilding essential parts in a ship, car or airplane. Overbuilding increases purchase prices as well as fuel costs.

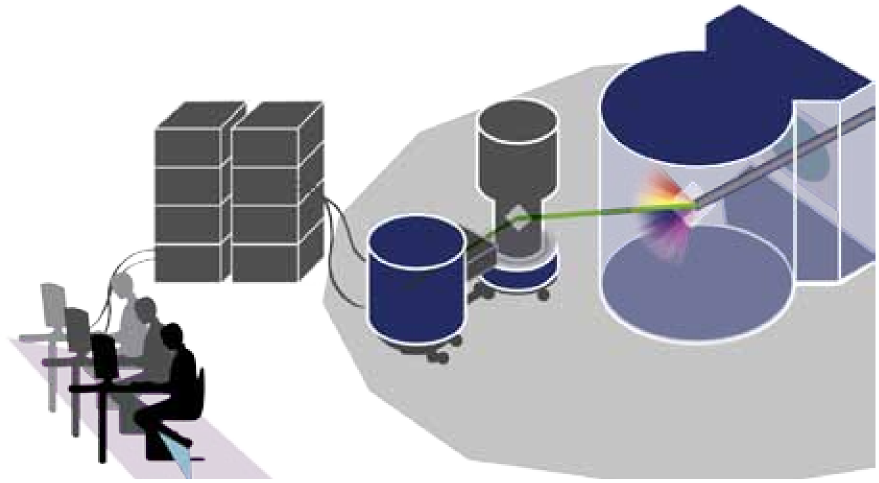
Prof. Dawson's long-term research program combines advanced simulations and experiments, to understand on a fundamental level how materials change or break when subjected to stress. His model will be more reliable because it will account for microscopic properties that current models neglect.

Over the past 15 years, Prof. Dawson has used the neutron beamlines at the CNBC for numerous measurements of stress in materials under realistic conditions of tension or compression. His recent experiments have used a new world-leading capability at the CNBC to observe stresses while applying tension or compression in two directions. These stress measurements provide vital data for Prof. Dawson to refine his model.

http://dx.doi.org/10.1016/j.jmps.2012.01.007

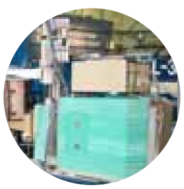
Sara Kenno measures stress distributions in welds on a replica of a ship hull plate with L-shaped stiffeners.

FACILITY UPGRADES



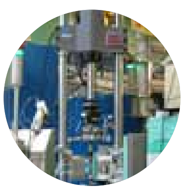
Our users' research programs are continually advancing and changing. Our users need our beamlines to be reliable, efficient and ready to meet the demands of research at the leading edges of their fields. They need to be able to create precise, realistic and sometimes strenuous conditions for their materials on the beamlines during their experiments, be they conditions of temperature, pressure, compression or tension, or magnetic fields.

We are responsive and continually renew our capabilities.



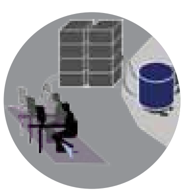
L3 Stress Scanner

The L3 Stress Scanner is the very best instrument in the world for three-dimensional, non-destructive mapping of stress distributions in engineering components, having undergone numerous upgrades over the past several years that have enhanced its capabilities and reliability. Notably, data collection has been improved by a new switchable-height, 32-wire detector with better shielding and a three-times-higher count rate. Examination of larger and heavier (up to 1.8 tonnes) samples is enabled by a new sample table and a laser dial gauge that is integrated into the control system.



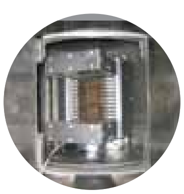
Servo-Hydraulic Load Frame

Complementing the upgrades to the Stress Scanner is the ability to study materials under conditions of biaxial loading using our new servo-hydraulic load frame and internal pressurisation system. Users are able to obtain critical data to validate models of polycrystal plasticity that predict how materials behave when subjected to load, which is a major topic of mechanical engineering research.



Data Acquisition and Control System

A multi-year effort is underway to maintain reliability by modernising the data acquisition and control system that underlies all the beamlines. Elements of the hardware such as motor controllers have been purchased and integrated using a user interface developed in-house that interfaces with a software system known as EPICS. EPICS has a proven track record for controlling scientific instruments in many large scientific facilities around the world. Initial testing of simple scans using these aspects of the new data acquisition and control system on a beamline has been successful.



Vertically-Focusing Heusler Monochromator

Our C5 Triple-Axis Spectrometer is used extensively for examining magnetism in materials. A project to build and commission a vertically-focusing Heusler monochromator for C5 was completed, which required a new monochromator table that could withstand the heavy weight of this monochromator and that had built-in features to reduce the potential high gamma radiation from the monochromator. The new Heusler monochromator is an excellent polariser with an overall flipping ratio of 25.

3-D Laser Scanner and Tracking System

A 3-dimensional laser scanner can now be used to create virtual representations of samples. When used in conjunction with a tracking system and implementation of SScanSS simulation and control software now commissioned for use on the L3 stress scanner, experiment set-up time is reduced, resulting in more effective use of the available beam time, particularly for complex-geometry samples. The system enables the correct positioning of samples to within ± 0.1 mm.

Closed-Cycle Refrigerator

The CNBC's newest closed-cycle refrigerator provides continuous temperature ranges between 1.5 K and 800 K, with no requirements for liquid helium or nitrogen. The new refrigerator can be fully operated automatically and remotely, is top-loading to enable fast sample changes, has a 70 mm diameter sample space, and can be adapted with a ^{3}He probe to reach lower temperatures, as low as 300 mK.

Students learning to apply neutron beams at the NRU reactor.

NEUTRON SCATTERING SUMMER SCHOOLS

"The summer school introduced me to an experimental tool that I need for my research on residual stresses in friction stir-welded lap joints for aerospace applications."

What brings dozens of graduate students and research scientists together from across Canada and the world for a week in the woods of the Ottawa Valley? Training on how to use the unique tools for world-class materials research available at the CNBC.

One aspect of enabling the user community is the provision of practical, hands-on training on neutron scattering techniques—experience that cannot be provided elsewhere in Canada. To achieve this goal, the CNBC has been holding biennial summer schools on neutron scattering for many years, and the latest schools were held in 2011 and 2013. These were the 11th and 12th Canadian Neutron Scattering Summer Schools at Chalk River.

"I am so glad I attended," said Michael Bach, a graduate student in mechanical engineering at Carleton University. "The summer school introduced me to an experimental tool that I need for my research on residual stresses in friction stir-welded lap joints for aerospace applications."

"My work involves complex models to predict the stress in these structures, and neutron beams will allow me to verify my predictions non-destructively," added Bach, who attended in 2011. "The hands-on experience at the beamlines at the NRU reactor was cool, and now that I have seen the facility and know the process, I plan to come back to do some experiments."

In fact, Michael came back to the CNBC for experiments four times over the next two years and completed his PhD.

Attendees of the 12th Canadian Neutron Scattering Summer School at Chalk River: June 2-7, 2013.

Although neutron scattering courses are held at other foreign neutron sources, the schools hosted by the CNBC attracted enthusiastic participants from across Canada, the United States and Europe. Twenty-seven students in 2013 and thirty-seven in 2011 attended the full week. Most of the participants were graduate students and post-doctoral fellows from the disciplines of physics, chemistry and materials science from Canadian universities. The students also included several materials scientists from AECL. The lecturers included CNBC staff and experts from the neutron beam community in Canada and the United States.

The school provides an overview of the theory and applications of neutron scattering in various scientific fields, covering a wide range of topics on theory, technique and instrumentation, rather than focusing on a narrow theme. The school provides the students, who may want to employ neutron scattering to advance their research, a chance to learn the fundamentals of neutron scattering and gives them a broad overview of the field.

The format of the school consisted of morning lectures followed by afternoon hands-on experiments on the spectrometers at the NRU reactor, aiming for a balance between lecture presentations and practical, hands-on demonstrations.

The 2013 school added parallel workshops on the last day to provide students with a more focused look into research examples within a scientific area most relevant to them. These workshops were attended by 39 researchers from AECL in addition to the summer school students. Students chose one of four sessions on magnetism and structural studies, industry applications, biological sciences, and surface sciences.

"The workshop was my favorite part of the summer school because it was highly relevant to what we're doing in the lab," said one student who attended the bio workshop.

The industry workshop built on the CNBC's close connection to AECL and the nuclear industry, which is the CNBC's most frequent client industry. Nuclear reactors for power and research face interesting materials challenges from inside the core and outwards through the balance of plant, resulting in a broad range of topics for study using neutron beams.

The schools were held in partnership with the Canadian Institute for Neutron Scattering and AECL.

"The workshop was my favorite part of the summer school because it was highly relevant to what we're doing in the lab."

PUBLICATION LISTS

The CNBC received notice of the following publications from CNBC staff and users. This list of publications arising from research conducted at the CNBC, with 27 papers published in 2011, 41 in 2012 and 39 in 2013, may not be exhaustive.

In addition, a series of technical reports from our users are available on the web site of the Canadian Institute for Neutron Scattering: http://www.cins.ca/expreports.html.

The references in the list and the technical reports are presented in the language in which they were written.

2011

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