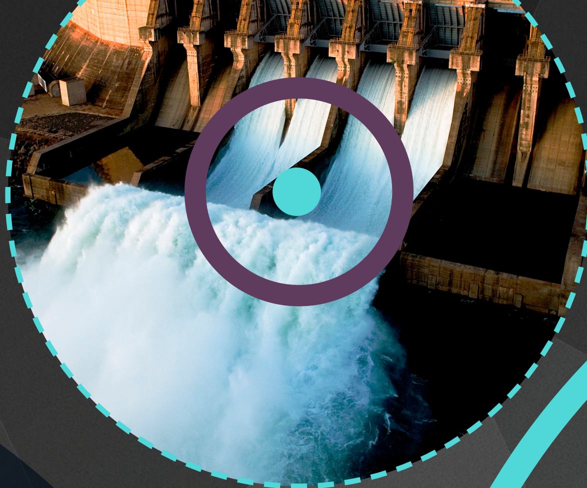
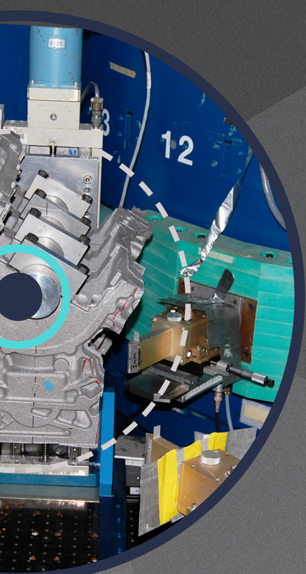
NEUTRONS.CA





CANADIAN NEUTRON BEAM CENTRE ACTIVITY REPORT

2014-2015

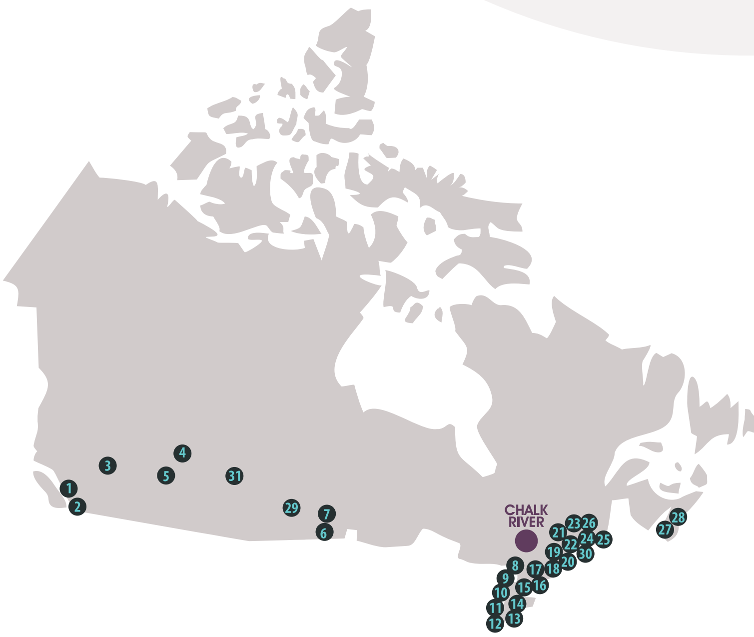
Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

CANADIAN NEUTRON BEAM CENTRE
Probing Materials for Science and Industry

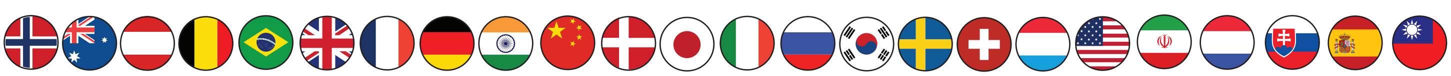
Probing Materials for Science and Industry

The Canadian Neutron Beam Centre (CNBC) at Canadian Nuclear Laboratories (CNL) 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.

As Canada's premier nuclear science and technology organization, CNL serves the nation as an enabler of business innovation and technology transfer. And, we foster the development of highly-qualified people for the knowledge economy to come.



1. University of British Columbia
2. Simon Fraser University
3. UBC Okanagan
4. University of Alberta
5. University of Calgary
6. University of Manitoba
7. University of Winnepeg
8. University of Guelph
9. University of Waterloo
10. Western University
11. University of Windsor
12. Brock University
13. McMaster University
14. Ryerson University
15. University of Toronto
16. Queen's University
17. Royal Military College
18. University of Ottawa
19. Carleton University
20. Université de Montréal
21. McGill University
22. Concordia University
23. École de technologie supérieure
24. Université de Sherbrooke
25. Université du Quebec a Trois-Rivières
26. Université Laval
27. Acadia University
28. Dalhousie University
29. Brandon University
30. École de Polytechnique de Montréal
31. University of Saskatchewan



The specialized 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 beamlines. 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 supports research by CNL for federal and industrial clients in sectors such as nuclear energy, aerospace, automotive, oil and gas, defence and primary metal production.

Canadian Neutron Beam Centre
Activity Report to the
Canadian Institute for Neutron Scattering
for 2014 and 2015

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Disponsible en français

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How a Neutron Beam Facility Works

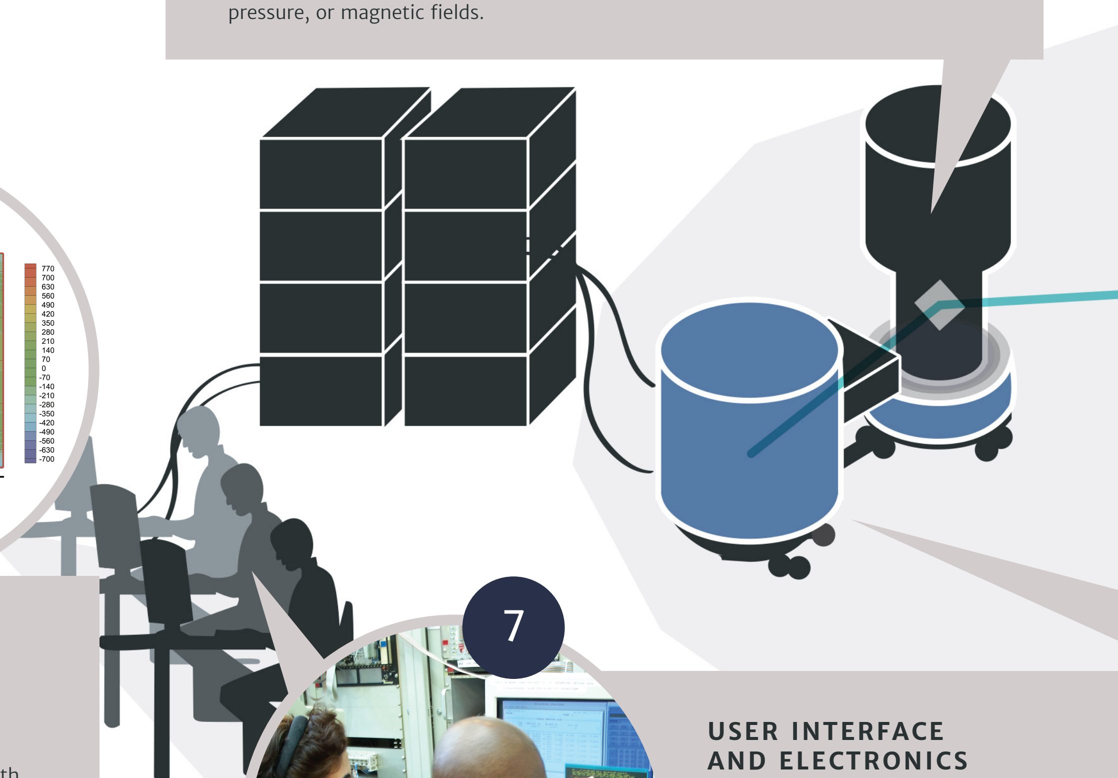
Researchers come from all over Canada and the world to probe materials with neutron beams to find solutions to challenges in health, industry, and science. From the initial inquires into the feasibility of an experiment to the final interpretation of results, CNBC scientists and technical staff provide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

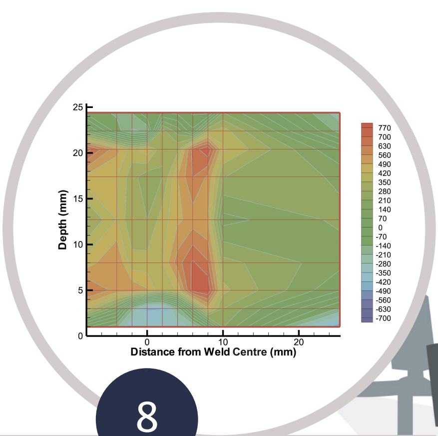
As neutrons pass through a material, the material changes the properties of the beam, such as the direction, energy, or magnetic polarization. By detecting these changes, researchers can deduce certain properties of the material such as atomic structure or stress.

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.





8

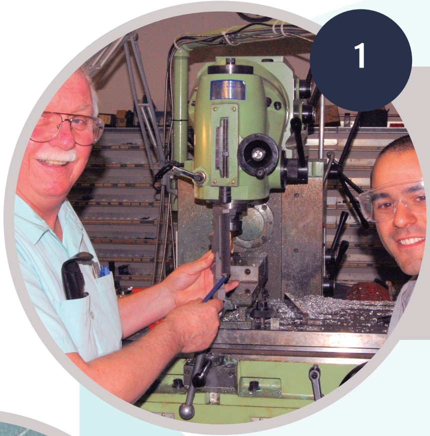
DATA ANALYSIS

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

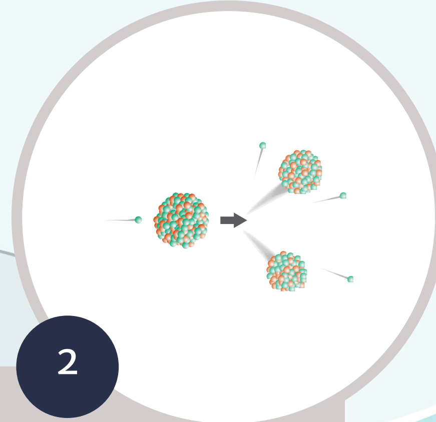
A specialized electronic system controls each portion of the beam line and collects the experimental data. Workstations provide the user interface to control the experiment and perform preliminary data analysis.



1

USER ARRIVAL

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



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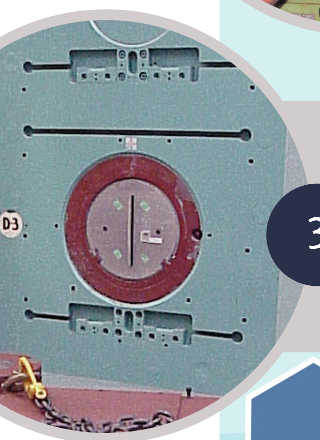
NEUTRON PRODUCTION

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

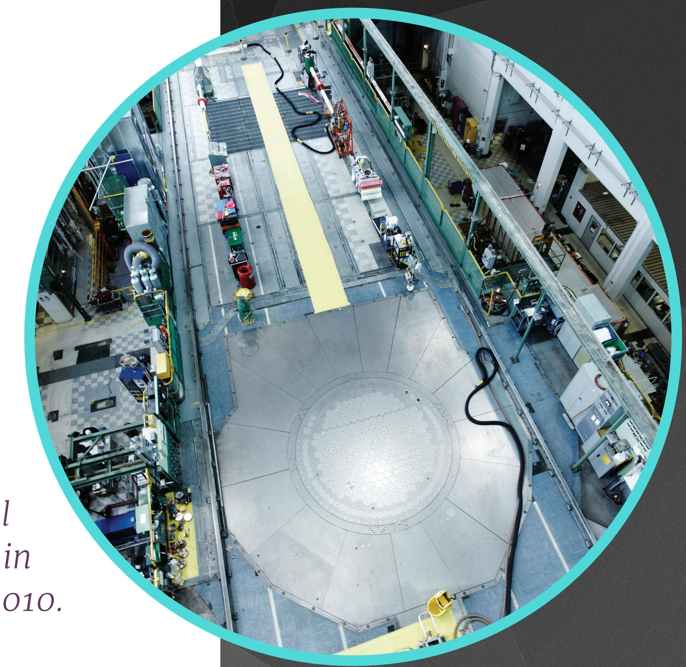
NEUTRON DETECTION

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

Director's Message

Maximizing Impact in Science and Industry with Neutron Beams from the NRU Reactor

The CNBC has delivered five solid years of providing access to neutron beams, collaborative research and educational experience to our user community since the National Research Universal (NRU) reactor at Chalk River returned to service in August 2010.



Top view of the NRU reactor, which supplies neutrons to the CNBC for materials research. The reactor is Canada's only major materials testing reactor, supporting nuclear energy research and development; it also produces several radioisotopes for medical applications.

The CNBC's solid performance has continued through the restructuring of AECL using a Government Owned, Contractor Operated ("GOCO") model. Canadian Nuclear Laboratories (CNL) is a new entity that has been operating the Chalk River site and other nuclear sites since November 2014. AECL continues to own these sites, while CNL employs nearly all of AECL's former workforce. In June 2015, Natural Resources Canada awarded a contract to manage and operate CNL to the Canadian National Energy Alliance (CNEA), a private-sector consortium. On September 13, 2015, the shares of CNL were transferred to CNEA, thereby placing CNL in the private sector.

Today, the CNBC is supported by expert researchers and technicians drawn both from CNL and from the National Research Council of Canada (NRC), with six neutron beam instruments and ancillary equipment owned by the NRC.

We expect the CNBC to continue operating until the NRU reactor ceases operation, currently scheduled on March 31, 2018.

NRC·CNRC

The National Research Council is a key partner with CNL in operating the CNBC.

I hope you will come along with us, proposing challenging experiments, encouraging young researchers to visit and learn everything they can from our warm and supportive team, and participating in the national conversation about the future of neutron scattering in Canada.

The procedure to apply for beam time at the CNBC continues as before for academic research in the public domain. Please visit www.cins.ca/beam.html. For access to neutrons for proprietary applications, please contact commercial@cnl.ca.

John Root, Director,
Canadian Neutron Beam Centre

Statistics for 2014-2015

Over the two years spanning 2014 and 2015, the CNBC delivered 2748 beam days. This beam time was divided among 213 experiments for 116 projects, with 92% of this beam time being delivered to user projects.

The CNBC retained strong engagement with the user community, with 399 individuals participating in research depending on access to the CNBC. These included 62 individuals from Canadian industry and government labs, as well as 138 individuals from 41 university departments spread among 22 Canadian universities in 7 provinces.

Of the 399 research participants, the remaining 199 were from 88 foreign institutions in 21 countries.

CNBC User Statistics

Community Function	Indicator	2011	2012	2013	2014	2015
Access	Number of users[1].	162	137	159	154	139
Canadian Access	Users from Canadian institutions.	61%	68%	66%	54%	63%
Participation	Research participants[2].	246	285	297	258	246
Leverage of International Collaboration	Research participants from foreign institutions.	48%	54%	49%	50%	44%
Canadian Acedemic Participation	Canadian universities represeted by research participants.	24	21	17	19	18
Academic Participation Across Disciplines	Canadian university departments represented by research participants.	36	35	36	29	29
Training of Highly Qualified People	Students and post-docs who visited the CNBC to conduct research.	36	34	27	26	16

CNBC Facility Statistics

Statistic	Definition	2011	2012	2013	2014	2015
Beamline Capacity	Reactor operating days multiplied by six beamlines.	1470	1440	1428	1416	1332
Beamline Efficiency	Percentage of available beam days occupied by projects.	86%	90%	96%	97%	89%
External Usage	Project beam time occupied by user-led projects.	91%	95%	90%	92%	93%
Average Experiment Duration	Beam time (beam-days) per allocation.	11.5	12.4	11.3	13.7	11.4
Project Demand[3]	New proposals received per year.	52	56	62	35	48

[1] A user during a given year is defined as an individual who visited the CNBC during that year to conduct an experiment, or who is a co-proposer of an experiment that ran during the year.
[2] A research participant during a given year is an individual who was a user during that year, or who is a co-author of a paper resulting from work carried out at the CNBC that was published during the year. This is a standardized measure for North American neutron facilities.
[3] About half of all 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 ELECTRICITY GENERATION

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.

Predicting the Reliability of Turbine Runners in Hydro Power Plants

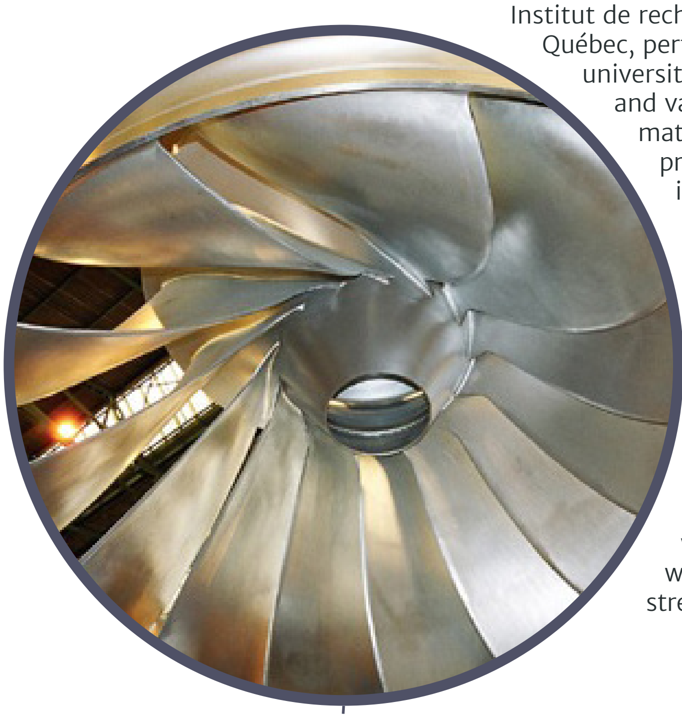
Hydro-Québec is using stress data from the CNBC to improve electricity generation from hydroelectric dams.

The water flow in hydroelectric dams makes turbine runners turn, and this motion is used to produce electricity. These critical parts are expensive, costing up to $10 million each, and if one fails, the lost electricity production can be very costly.

To ensure reliability, Hydro-Québec asks turbine manufacturers to show that their turbines will last at least 70 years. But how can that be done without having to wait 70 years?

Traditionally, the hydraulic engineering community has relied on analysis of the stress under a full load to predict reliability. This method has worked well, and early failures of turbines are rare. However, when failures do occur, the failure mechanism is analyzed—and is most frequently linked to the constant change in load while in service. That's why manufacturers and large utilities are improving turbine reliability using computer models to perform fatigue life calculations (i.e., to predict how many cycles of loading and unloading the turbine can withstand before a detectable crack appears).

Hydropower is created when the water in a reservoir falls down and passes through a turbine.



A turbine runner.

Institut de recherche d'Hydro-Québec (IREQ), the research arm of Hydro-Québec, performs research in partnership with manufacturers and universities to gather the experimental data needed to build, improve and validate these models. The data collected includes data about the material properties and how these properties change as a result of processes such as welding or subsequent heat treatment, which is used to increase the toughness and ductility of welds and to reduce residual stresses.

One research team, which included IREQ and École de technologie supérieure, accessed the Canadian Neutron Beam Centre to study the effectiveness of heat treatment after welding stainless steel with a filler material. The research team needed to know how stress created by the welding process deep inside the steel would be affected by the heat treatment. The results of the neutron beam measurements showed that welding can, in fact, produce a desirable stress distribution, and also that, after heat treatment, the magnitude of the stress was significantly relieved. The neutron beam data correlated well with the team's findings that used other methods for determining stress, thereby providing high confidence in the results.

Stress data from CNBC measurements are being used today in manufacturers' fatigue life calculations, making these calculations more reliable. The data shows that the optimization of manufacturing processes can improve the lifetimes of turbines, often without any increase in cost.

IREQ published this research in 2010, thus providing residual stress data that is now incorporated into manufacturers' fatigue life calculations. Alstom, a prominent manufacturer of hydraulic turbines, and Hydro-Québec have continued a large research program aimed at improving their understanding of the factors influencing runner lifetime. The residual stress measurements from the CNBC and the fracture mechanics properties measurements brought useful data to this program, making today's lifetime calculations more reliable. Further, they have showed that optimization of manufacturing processes like welding and heat treatment can improve the lifetime of turbines, often without any increase in cost.

DOI:10.1016/j.msea.2010.06.035

Enhancing the Reliability of Power Plants in the United Kingdom

Operators of nuclear power plants use stress data from the CNBC to ensure safe, reliable and economic operations.

One of the ways that electricity generators ensure safety is by making conservative decisions to resolve even the slightest safety concern. Rare and unexpected issues—even minor ones—in nuclear power reactors around the world can sometimes result in temporary outages to investigate and respond. When reactor operators choose to forego electricity production, which can represent tens or sometimes hundreds of millions of dollars, it shows how important safe operations are to them.

Operators sponsor or perform research to improve predictions of the behaviour of materials over decades so that there will be fewer unexpected issues that lead to down time. In this way, enhancing the reliability of power plants goes hand in hand with safety and cost-effectiveness.

The Heysham 1 power station in Lancashire, England (operated by EDF Energy) houses two advanced gas-cooled reactors that together produce 1150 megawatts of electricity.

Stress data from the CNBC helped EDF Energy to explain observations of accelerated crack growth rates. Now, EDF Energy is continuing to use that data in further studies aimed at reducing unexpected plant down time, thereby enhancing the safety and cost-effectiveness of operations.

One factor that can lead to cracks in metal components over long periods of time is called 'creep,' in which the shape of a metal deforms very slowly. The creep can affect the growth of cracks and eventually limit the useful life of high-temperature components, such as those near the core of an advanced gas-cooled reactor (AGR).

EDF Energy in the United Kingdom collaborates with Professor John Bouchard of the Open University to study the behaviours of materials relevant to AGRs, thereby generating knowledge for safety cases presented to the nuclear power regulator.

Prof. Bouchard's team accessed the Canadian Neutron Beam Centre in 2012 to quantify how residual stress influences creep crack growth rates at high temperatures. The CNBC examined test specimens made by electron beam welding of a pipe made of Esshete 1250, a type of stainless steel, that had undergone prolonged exposure to high-temperature service conditions. Prof. Bouchard applied two complementary methods of determining a portion of the stresses, which agreed well with the neutron data and provided high confidence in the results. The full stress distribution along the direction of the crack, as obtained by the CNBC, was then used to show that electron beam welding introduces high stresses—which inevitably produce large effects on fatigue, fracture or creep crack growth behaviour.

EDF Energy then applied the stress measurements from the CNBC to calculate the degree to which stress contributes to the creep crack growth in the specimen. The findings demonstrated that the stress from such electron beam welds does indeed accelerate creep crack growth rates, helping EDF Energy to explain earlier observations of crack growth rates in replicas of pipe weldments. Now, EDF Energy is continuing to use the stress data in further studies that use computer modelling to simulate the effects of stress (along with other contributing factors) on crack growth—a step along the way to reducing unexpected down time and enhancing the safety and cost-effectiveness of its power plants.

DOI: 10.1007/s11340-012-9672-7

PROBING MATERIALS FOR AUTOMOTIVE MANUFACTURING

Applying Neutron Beams To Solve Automotive Challenges

Years of research on technologies to optimize the production of lightweight car engines and other auto parts may soon pay off with big dividends for our automotive partners.

Neutron beams, like no other tool, can be used to non-destructively probe deep inside engine blocks. This technique allows auto manufacturers to determine the amount of stress in the material at any given point, which is a key factor in the reliability of an engine.

Nemak Canada's technologies, which are being developed with the CNBC, will speed production and reduce energy usage, saving millions in manufacturing costs.

Neutrons help Nemak Canada to speed engine manufacturing.

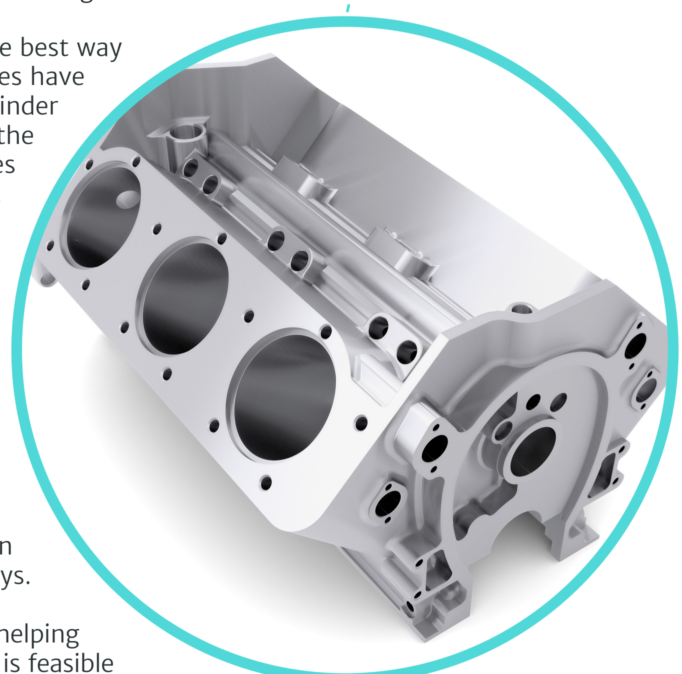
According to Nemak Canada, the technologies being developed in partnership with the Canadian Neutron Beam Centre—technologies that are now close to being implemented—will speed production times and reduce energy usage, thereby saving millions in manufacturing costs.

In one line of research with Nemak, the objective was to find the best way to build robust V-6 aluminum engine blocks. These engines have extremely low tolerance for distortion in the shape of the cylinder holes in the block. Stress relief methods are used after casting the block to increase stability, and yet each manufacturing step comes with its own costs and impacts on the materials properties. To improve upon current manufacturing practices, the team needed to understand more clearly the factors contributing to stability.

Nemak and its research partners from Ryerson University accessed the CNBC's neutron beams for several studies to acquire and interpret the neutron diffraction data. These studies included elucidating the stress distribution and microstructure in new aluminum alloys and in engine blocks, namely by examining the materials before, during and after stress relief methods such as heat treatment. Additionally, they included pioneering observations of microstructural evolution during solidification of the alloys.

The results were vital contributions to the success of the research, helping Nemak to determine that simplifying the heat treatment process is feasible without compromising reliability. Nemak is now moving forward to validate the new process by performing final tests, such as putting a prototype engine block in a test vehicle, in advance of the engine being used in vehicles sold to customers.

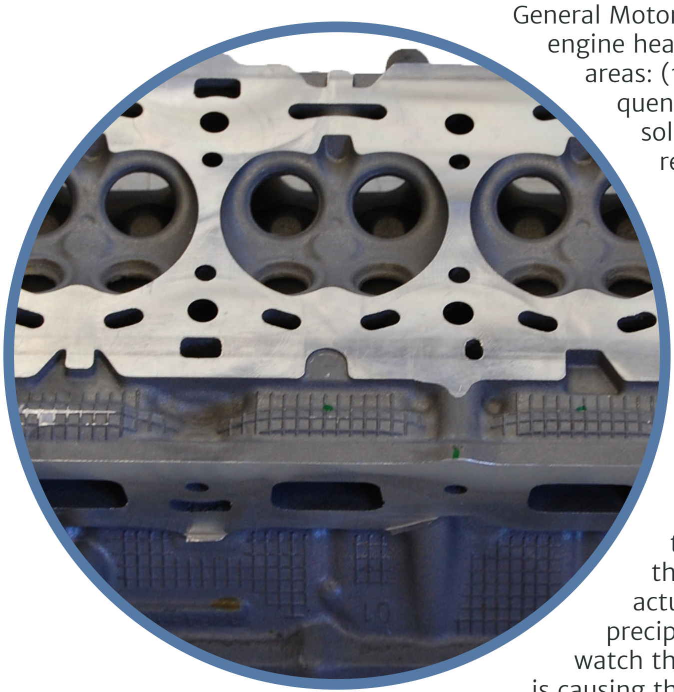
DOI:10.1016/j.matlet.2015.05.094



A V-6 aluminum engine block.

Neutrons help General Motors to accelerate engine development.

General Motors (GM) uses neutron beams to accelerate the development of engine heads and blocks. These projects span three primary research areas: (1) evaluating the effectiveness of heat treatment and quenching methods; (2) directly observing phase precipitation during solidification; and (3) creep testing to make better predictions of reliability over the long term.


GM cylinder head.

In the first area of evaluating the effectiveness of heat treatment and quenching methods, the CNBC's measurements clearly falsified a hypothesis for GM—specifically, that the air quenching of cylinder heads would provide a benefit over water quenching because of an overall reduction in residual stresses. The results showed that, with air quenching, significant stresses remained deep inside the cylinder heads, at a depth of about one centimetre.

In the second research area of directly observing phase precipitation during solidification, GM uses modelling software to try to predict the properties of the components or alloys after they solidify, although sometimes these models fail to predict the actual results. Neutrons, however, can uniquely identify phases that precipitate during solidification. In other words, they allow GM to watch the solidification process experimentally to better understand what is causing the discrepancies.

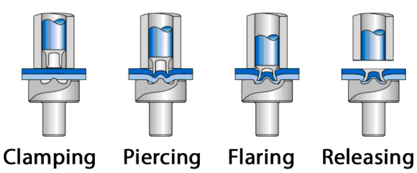
The CNBC's measurements clearly falsified a hypothesis for GM concerning which of two manufacturing methods would be more effective in reducing residual stress in cylinder heads.

The third research area is concerned with creep testing, which in essence means determining how the shape of a part may change over time and eventually fail or cause problems. The neutron beam experiments allow GM to look at how the arrangement of the atoms changes in the material to better understand how these changes take place.

DOI: 10.1002/9781118888438.ch60

Neutrons help the Ford Motor Company to investigate riveting techniques for lightweight vehicles.

The CNBC has an ongoing research project with the Ford Motor Company to examine new ways of joining dissimilar materials for use in lightweight vehicles. For example, self-piercing riveting (SPR) is a leading alternative to traditional welding methods and has been widely used by Audi, Mercedes, BMW and Jaguar on their aluminum cars and SUVs. SPR joints have excellent mechanical properties and high fatigue resistance. Prior to the CNBC's involvement, however, the 3D residual stress field in a mixed metal SPR joint had never been experimentally studied, making predictions for the fatigue life of such SPR joints difficult. Thus, Ford turned to the CNBC's neutron beam capability because other ways of determining stresses were too difficult due to the complex geometry and number of different materials involved. Ford plans to use the results from the neutron analysis to validate its existing residual stress prediction method and to document these findings to inform broader manufacturing processes.



Left: Illustration of applying a self-piercing rivet to join two materials.

Right: Cross-sectional image of a self-piercing rivet joining sheets of steel and aluminum.

CNBC researcher honoured for automotive contributions.

The value of the CNBC's contributions to improving automotive technologies is being recognized by peer organizations and partners like the Canadian Academy of Engineering (CAE), which recently bestowed one CNBC researcher with a prestigious honour. Indeed, CNBC researcher Dr. Dimitry Sediako was inducted as a Fellow of the CAE in June 2014 in recognition of his contributions to improving manufacturing technologies in engine block casting and heat treatment, among other achievements. To conduct this research, Dr. Sediako has built partnerships with researchers from Nemak, GM and Ford, among others, as well as with universities (i.e., Ryerson University, the University of British Columbia, the University of Waterloo and McGill University) and Canmet Materials Laboratory—all valuable partners that have contributed their own tools and expertise in metallurgy, mechanical testing and computer modelling.

Dr. Dimitry Sediako prepares to measure stress in a GM cylinder head at the L3 neutron beamline.

MagNET makes breakthrough in lightweight car doors.

The Canadian Neutron Beam Centre joined forces with materials science and engineering experts across Canada to produce light-weight magnesium prototypes for the car market. Magnesium is not only plentiful but also very light, and thus cars made of it will use much less fuel. The network of researchers, called MagNET, was led by Professor Warren Poole of the University of British Columbia (UBC). Together with UBC, École Polytechnique, the University of Waterloo and McMaster University, the CNBC enabled a number of MagNET projects that characterized several magnesium alloys under various in situ conditions, including solidification and multiaxial loading.

UBC's Prof. Warren Poole and other members of the MagNET Project studied how to develop lightweight magnesium car parts that could be widely adopted by the auto industry.

The close collaboration between MagNET researchers and General Motors, Magna International and Magnesium Elektron enabled a breakthrough demonstration—namely, using a production-scale die to form a car door from a magnesium alloy sheet in less than ten seconds, which is ten times faster than existing processes. For industry, this is an important step on the road to the wide-scale commercial applications of magnesium sheet. The achievement was recognized by a 2014 Award of Excellence from the process division of the International Magnesium Association (IMA). The award was presented at the IMA's annual meeting in Munich, Germany in June 2014.

Enhancing the Reliability of Retrofitted Utility Vehicles

Following research at the CNBC, Nor-Mar Industries has received approval for, and successfully implemented changes to, welding protocols to deliver premium-quality products.

A utility truck retrofitted by Nor-Mar Industries.

Nor-Mar Industries strips trucks to custom fit them with cranes, heavy-duty equipment, storage and other features needed by clients in the forestry, construction, mining and oil sectors. Before delivery to the client, strength and toughness of the welded frames must satisfy safety regulations.

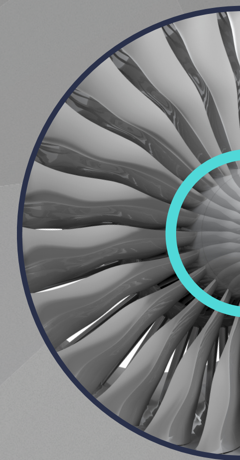
Nor-Mar recently finished a research project with Professor Lukas Bichler of the University of British Columbia to better understand Nor-Mar's manufacturing procedures and practices, as well as to develop protocols to enhance the quality of its welded frames, made of AR200 steel. Welding methods are known to create stresses that must be minimized to prevent inclusions or defects, such as fissures, tears or porosity.

Because retrofitting vehicles is a stringently regulated activity, the ability to measure stress in welded truck frames will continue to be needed.

The research team accessed the Canadian Neutron Beam Centre in August 2013 to non-destructively determine the residual stresses. The project not only provided scientific evidence that Nor-Mar's welding practices were on track, but also identified areas that could be enhanced at the sample preparation stage.

Subsequently, Nor-Mar modified its welding protocols, which have now been approved by the Canadian Welding Bureau for use. As a result, Nor-Mar has successfully implemented the needed changes in order to deliver a premium-quality product to its clients.

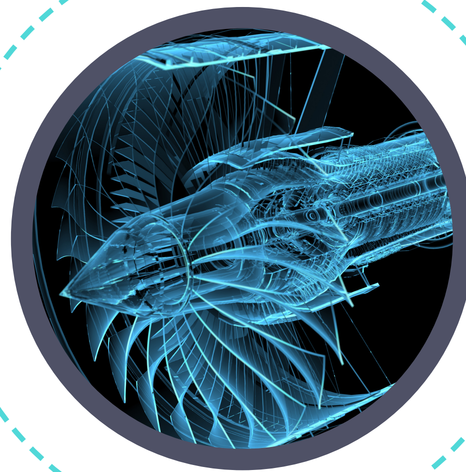
Industries that retrofit vehicles operate in a stringent regulatory environment. Thus, it is likely that knowledge of the stress in welded truck frames will continue to be needed as these industries improve their practices, develop new products and respond to changes in regulations.



PROBING MATERIALS FOR AEROSPACE MANUFACTURING

Reducing Rework and Scrap Costs in the Production of Airplane Parts

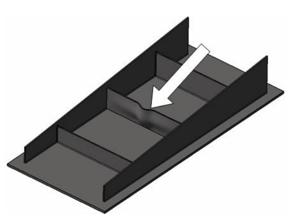
Aircraft manufacturers sponsor researchers who are using stress data from the CNBC to evaluate methods of preventing distortion in thin aluminum parts.



Boeing once estimated the cost of reworking or scrapping parts with small distortions at about $300 million or more per year. The high cost of not making an airplane part exactly right the first time can be explained by low production volumes over which the high costs of developing new products and ensuring quality are spread. The cost of quality is high because safety and reliability are critical. The cost of developing new parts is also high because trends to minimize weight and optimize performance push the limits of materials—and our knowledge of them.

Not surprisingly, then, parts with slight distortions can be rejected or reworked if they don't fit properly or if they might not be able to bear the loads required of them. Distortions can be especially frequent in parts with thin walls, such as those used in a plane's structural frame. That is because machining creates stress near the surface; for a wall that can be as thin as 0.4 millimetres, most of the wall is near the surface, so distortion often results.

To prevent distortions, one solution is to make the walls thicker; however, the increased weight would reduce fuel efficiency and performance. A second solution involves painstaking multiple-step machining processes that drive up the cost.



Thin-walled parts are susceptible to shape distortion.

To find a better solution to the challenge of distortions, Bombardier and the National Research Council of Canada sponsored Professor Jean-François Chatelain's research team at École de technologie supérieure. Bombardier also provided support for a graduate student to work in both Prof. Chatelain's lab and at its own industrial facility. The team set out to study how making thin-walled parts from aluminum alloys creates stress, which is a major cause of distortion—and which can be added to by each of many manufacturing processes.

Prof. Chatelain's team accessed the Canadian Neutron Beam Centre to non-destructively obtain stress data for two 'work-in-progress' model parts (i.e., thin-walled parts that replicate those used in large sections of airplane structures). Both work-in-progress parts were made of 7475-T7351 aluminum alloy. However, the alloy of the first work-in-progress part was made from standard aluminum billets, while the alloy of the second part was made using a special processing recipe to reduce any initial stress.

Using laser scanning to measure any changes in shape that resulted from the machining, the research team examined the two replica parts before and after machining operations were conducted. The team found the amount of distortion to be directly related to stress from machining measured at the CNBC —and also that the choice of alloy made a big difference.

Indeed, the part using the specially made aluminum had much lower levels of stress and distortion.

A graduate student aligns an aluminum sample for stress measurement on the L3 neutron beamline.

This research, published in 2012, suggests that rework and scrap might be reduced in thin-walled structural components by focusing on stress reduction and using specially made aluminum that is nearly free from initial stress.

Building on these findings, Prof. Chatelain's team is continuing to work in partnership with Bombardier to examine the relationship between stress and distortion in parts machined from sheet metal.

www.naun.org/main/NAUN/mechanics/17-425.pdf

Enhancing the Lifetime of Aircraft Parts

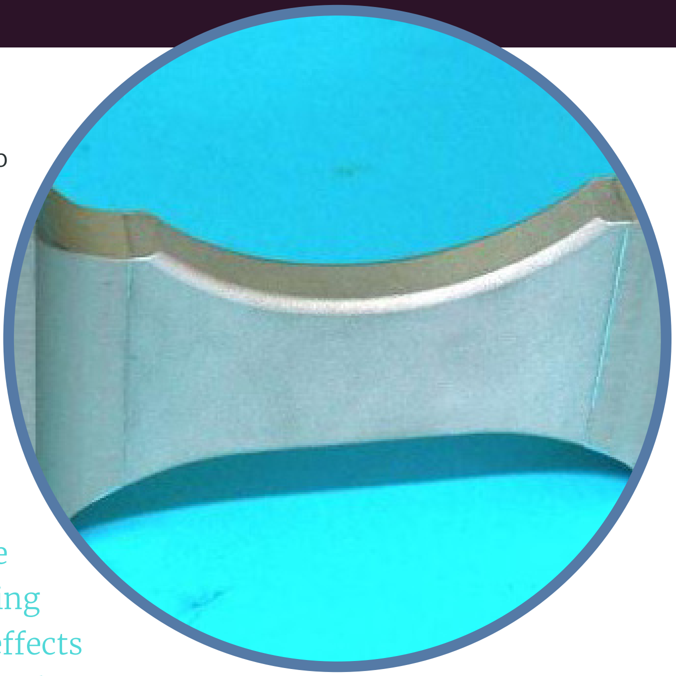
Aircraft manufacturers sponsor research because they need stress data to improve computer models of the lifetime of their parts.

Increasing the useful life of aircraft parts can reduce maintenance costs, which can be significant considering that any change to an aircraft must be carefully controlled to assure regulators of passenger safety. Thus, major aircraft manufacturers sponsor research at universities to generate a better understanding of materials, which can help the industry to develop parts with longer lifetimes.

One such manufacturer sponsored a research team led by Professor Michael Fitzpatrick of Coventry University in the United Kingdom. This team examined the effectiveness of surface treatments used to increase the lifetimes of parts like the aluminum skin on airplane wings and fuselages. The team also wanted to see whether a computer model could predict how these surface treatments would create stress in aluminum specimens, since such stress affects a part’s fatigue life (i.e., how long a part can withstand varying pressures over many flights).

"A big reason I came to the CNBC was I could get time on a beamline faster there than at any other diffraction facility in the world."

Because getting accurate stress measurements is crucial, Stefano Coratella, a graduate student in Prof. Fitzpatrick's team, accessed several major neutron beam and x-ray facilities around the world to gather data for various portions of the research. Coratella came to the Canadian Neutron Beam Centre to examine how combining two different surface treatments, known as shot peening and laser shock peening, would affect stress. Used individually, these treatments introduce 'compressive' stress, which helps to make the material last longer. The latter treatment is a newer technique that has been used successfully to improve fatigue life for gas turbine engine compressors and fan blades.



An aluminum specimen with a milled notch and surface treatments ready for examination with neutron beams at the CNBC.

The aircraft manufacturer that sponsored the research was interested in knowing whether applying both methods could further enhance the positive effects of each individual technique.

"A big reason I came to the CNBC was I could get time on a beamline faster there than at any other diffraction facility in the world," said Coratella.

Using specimens provided by the aircraft manufacturer, Coratella was able to use the stress data collected at the CNBC to demonstrate that the computer model was more effective at predicting the stress induced by the laser shock peening of an aluminum sample than it was at predicting the stress induced when shot peening was applied after laser shock peening. More research is required to understand why that is the case, and also so that the computer model can be improved.

PROBING MATERIALS FOR NUCLEAR WASTE MANAGEMENT AND NON-PROLIFERATION

Solving the Mystery Flask: A Forensic Challenge To Reduce Nuclear Liabilities

The CNBC is enhancing its neutron imaging capabilities to see inside concealed objects. Identifying unknown radioactive material reduced the cost of a long-term waste management liability for the Government of Canada and demonstrated new capabilities.

Neutron imaging works much like light in a camera, except the neutrons easily pass through dense, solid materials that even x-rays cannot penetrate.

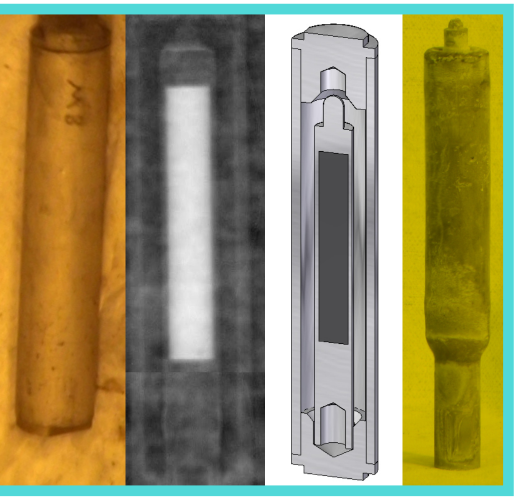
Canadian Nuclear Laboratories was recently presented with an unidentified container that predated modern standards for storage of radioactive materials. The container was dubbed 'the mystery flask' or 'the legacy flask'. When opened in a hot cell, the legacy flask was found to contain four radioactive capsules of unknown origin, with no records to identify them or their contents. The radiation from the capsules indicated cesium, suggesting they contained irradiated fissile material.

> To properly manage of such material, CNL needed to know what the material was and how much of it was inside. But without knowing more about what was in the capsules, it was difficult to know whether—and how—they could be safely opened.

A research team from CNL was formed to solve this riddle. To determine the four capsules' internal structures and contents without opening them, the researchers applied x-ray fluorescence spectroscopy combined with three techniques that used neutron beamlines at the Canadian Neutron Beam Centre: neutron diffraction, neutron imaging and delayed neutron activation analysis.

Neutron imaging revealed that each capsule contained a cylindrical core surrounded by an aluminum canister. This canister-core assembly was contained in the aluminum capsules and loosely retained by the end caps.

Top to bottom: The unidentified 'legacy flask'; the view inside of the flask reveals four capsules in a chandelier; one of the capsules removed from the chandelier.



Left to right: Photograph of the capsule; neutron image of the capsule containing a canister; illustration of the capsule reconstructed from the neutron images; photograph of the canister after the capsule was opened, confirming the accuracy of the neutron images and reconstruction.

Combining the results of all four techniques, the CNL team determined that the canister cores contained irradiated thorium and uranium, and how much of each. The team was then able to determine that the canisters were likely irradiated in the late 1950s as part of an early isotope production program.

The value of this knowledge to the Government of Canada's Nuclear Legacy Liability Program was significant. Firstly, it enabled the proper recording of the capsules' contents in the nuclear materials inventory. Furthermore, it determined how the capsules could be opened safely and also reduced the number of tile holes required to store the fissile material by 75 percent.

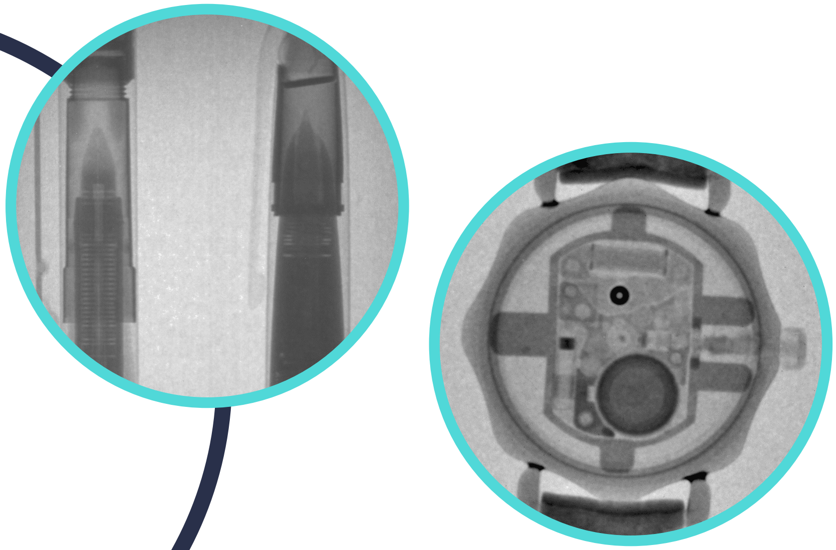
This project also served to demonstrate the CNBC's capabilities in neutron imaging and neutron activation analysis. As a result, these capabilities are now being further developed to be able to serve more clients. In fact, Defence Research and Development Canada (DRDC) has provided funds to purchase equipment to upgrade the CNBC's neutron imaging capability because neutron imaging will be valuable for meeting other nuclear forensic challenges, such as identifying nuclear materials in containers found by police or military personnel.

The knowledge gained enabled CNL to:

(1) Properly record the capsules' contents in the nuclear materials inventory.

(2) Determine how the capsules could be opened safely.

(3) Reduce the number of tile holes required to store the fissile material by 75 percent.

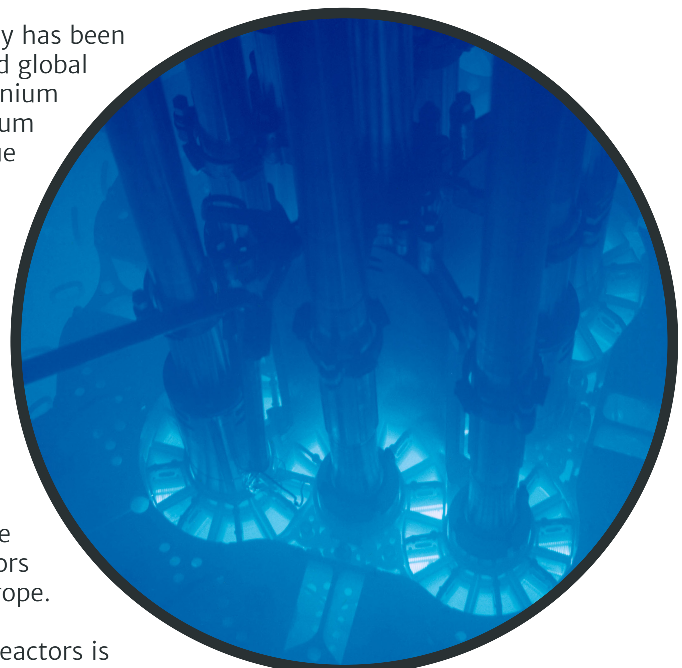


The first neutron images taken using the new neutron imaging camera funded by DRDC. Left to right: Pens; a wrist watch.

Assisting Non-Proliferation Through Nuclear Fuel Development

Studies of nuclear fuel at the CNBC help Canada to contribute to global nuclear security.

Over the past few decades, the international community has been cooperating to reduce nuclear proliferation risks. One U.S.—led global initiative is to reduce or eliminate the use of highly enriched uranium (HEU) for civilian purposes. Historically, highly enriched uranium was a commonly used fuel for research reactors, which continue to be used for testing environments to qualify materials for the nuclear power industry; to produce medical or industrial isotopes; and to produce neutron beams for research. In order to maintain the value of these research facilities, significant efforts have focused on converting them to use low-enriched uranium (LEU), which poses much less risk of being diverted for use in weapons.



The U.S. is studying the feasibility of converting its Advanced Test Reactor (pictured) at Idaho National Laboratory to use low-enriched uranium.

Between 2004 and 2014, all 20 of the research reactors in the U.S. capable of being converted to use existing LEU fuel were converted, leaving five high-performance research reactors still using HEU. Outside of the U.S., at least 100 facilities have either been converted from HEU to LEU or have been shut down. About five high-performance research reactors that use HEU remain in Western Europe.

Research into new LEU fuels for these high-performance reactors is currently being conducted. Not only must these new fuels have a higher uranium density to offset the lower enrichment, but they also need to be tested and qualified for service.

A hot cell for examining highly radioactive materials on the the neutron beamline.

Canadian Nuclear Laboratories has tested candidate LEU fuels in its NRU reactor. One promising new fuel consists of uranium–molybdenum ("U-Moly") particles inside aluminum plates. However, development of this U-Moly fuel was set back when the fuel failed during testing.

To determine why it failed, CNL accessed the Canadian Neutron Beam Centre to examine the failed fuel, which was now highly radioactive. CNL and the CNBC developed a special hot cell to contain the radiation safely during the neutron beam measurements. Neutron beams were used to determine the crystallographic phases within the fuel because neutrons provide a high penetration depth (as compared to x-rays, for example, which would be absorbed at the surface of the fuel).

Knowing why the fuel failed is now guiding CNL's ongoing development of a new fuel design to eliminate or reduce the reactions between the U-Moly and the aluminum.

The measurements helped CNL to identify how U-Moly behaves in a highly radioactive reactor core, including the chemical reactions that occur between the U-Moly particles and the aluminum. The results provided strong evidence that these chemical reactions—which occurred at a rate that was faster than expected—ultimately led to the fuel failure. Knowing why the fuel failed is now guiding CNL's ongoing development of a new fuel design to eliminate or reduce the reactions between the U-Moly and the aluminum.

CNL has also accessed the CNBC to examine uranium silicide fuels, which have been used successfully in the NRU reactor for decades and are therefore of great interest as a model for the conversion of other reactors. When a rare fuel failure occurred in the NRU reactor, the CNBC assisted in the root cause analysis by examining the chemical composition in the highly radioactive fuel sample. The results clearly indicated that the sample's chemical composition was within specifications and therefore not the cause of the failure, guiding CNL's search for the root cause elsewhere.

PROBING MATERIALS FOR ENERGY TECHNOLOGIES

Water Uptake and Swelling in Fuel Cell Membranes

Researchers from universities access the CNBC to obtain fundamental insights into materials used for clean energy technologies.

Cars powered by hydrogen instead of gasoline are starting to enter the market. The Toyota Mirai, launched in California in the fall of 2015, was one of the first such vehicles to be sold commercially. It can travel 500 kilometres on its two fuel tanks, which together store a total of 5 kilograms of hydrogen. The car generates electricity in a fuel cell by combining the hydrogen with oxygen from the air to produce water and energy.

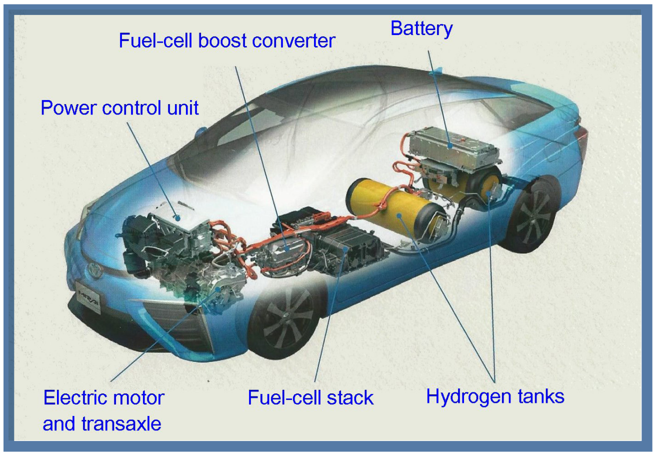
Over 100 hydrogen fuelling stations are expected to be built in California by 2020. However, there are numerous research challenges that still require attention, including a focus on ensuring the reliability of the fuel cells and boosting their lifetimes. While fuel cells are well established for applications that require steady power, the amount of power required by a vehicle fluctuates greatly with speed and acceleration. This 'load cycling' in a vehicle reduces the lifetime of a fuel cell by ten times as compared to constant loads. Other factors that can impact the lifetime of fuel cells include pollutants in the intake air, low humidity, high temperatures, and cycles of drying and wetting of the fuel cell membrane.

The UBC research team observed a swelling hysteresis in the fuel cell membrane that had not been seen before.

Professor Walter Merida at the Clean Energy Research Centre at the University of British Columbia led a research team to study the effects of humidity and temperature on fuel cell membranes. The team applied the neutron reflectometry technique available at the Canadian Neutron Beam Centre to determine how humidity and temperature influenced water intake and swelling in a nafion™ model membrane that was only 15 nanometres thick. Through the use of neutron reflectometry, the researchers made two important observations. First, they observed that upon heating the film at high humidity,its thickness expanded by 48 percent. This expansion was greater than any previous observations, which had been conducted at room temperature. Secondly, the team observed that the heated membrane did not shrink back to its original thickness when cooled to room temperature, indicating an irreversible change to the membrane's structure that had not been seen before.

The team is planning further experiments to investigate these findings in more detail, which may shed light on the factors affecting fuel cell performance in vehicles.

DOI: 10.1021/acs.langmuir.5b00764



Cutaway of the Toyota Mirai showing the fuel cells and hydrogen tanks.

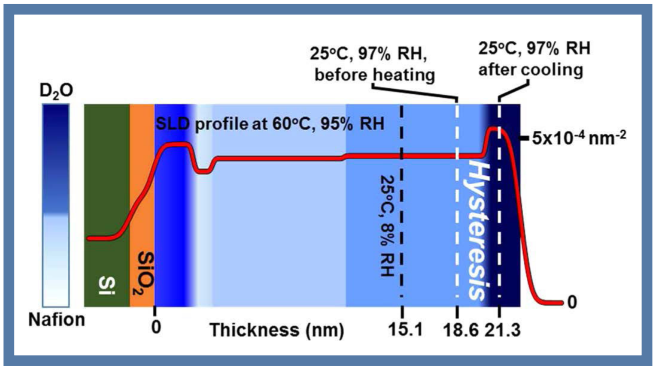


Illustration of the thickness in nanometres (nm) of the nafion™ model membrane depending on conditions of humidity (RH) and temperature (°C), as determined from the scattering length density (SLD) observed by neutron reflectometry.

Making Mobile Phone and Laptop Batteries Safer and Longer Lasting

*A lithium-ion laptop battery.

An international research team led by Hydro-Québec accessed the CNBC to obtain fundamental insights into how to make better materials for batteries.

Mobile phones, laptops and other portable devices widely use rechargeable lithium-ion batteries. These batteries require built-in safeguards against overheating, which could cause the battery cell to rupture or even catch fire in extreme cases.

Hydro-Québec is exploring the use of lithium iron phosphate ($LiFePO_4$) as a cathode in these batteries. This material could eliminate concerns about overheating, while also increasing performance. One of the challenges in using lithium iron phosphate is to find an efficient method of producing these crystals to have high purity as well as uniform size and shape distribution.

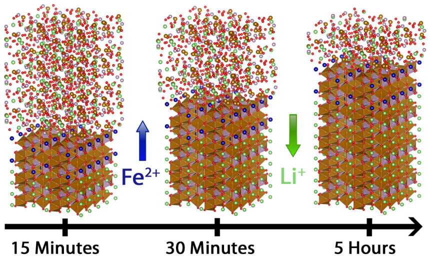
One method involves crystallizing lithium iron phosphate out of solutions at high pressures and temperatures (around 180 °C). This hydrothermal method meets some of these criteria and is cheaper than most other methods. It takes many hours, however, and many of the crystals are formed with defects.

To understand how the hydrothermal synthesis of lithium iron phosphate can be improved, researchers from IREQ, Hydro-Québec's research arm, accessed the Canadian Neutron Beam Centre to examine the crystal structures of intermediate materials created at various intervals during synthesis. They then repeated these studies while introducing calcium as a catalyst.

Using x-rays and electron beams, the researchers determined that the calcium was having effects on the shapes of the crystals. Through a combination of neutron beam and electron beam methods, they were able to identify the intermediate materials and map out the development of lithium iron phosphate in each of the two synthesis methods (i.e., both with and without the calcium catalyst).

They found that the addition of calcium ions facilitates the elimination of the defects from the lithium iron phosphate crystals. The evidence led to the hypothesized mechanism illustrated in the schematic representation. According to this hypothesis, the antisite defects are eliminated by the cation exchange composed of the deintercalation of Fe^{2+} ions and the intercalation of Li^{+} ions. This study provides fundamental knowledge to support the development of the fast, low-cost production of high-quality lithium iron phosphate—a critical material for better, safer batteries for portable devices.

DOI:10.1016/j.nanoen.2015.06.005



Schematic representation of the elimination mechanism of antisite defects in lithium iron phosphate ($LiFePO_4$). The blue spheres represent iron ions and the green spheres represent lithium ions.

PROBING MATERIALS FOR OIL & GAS

Neutron Beams Inform Lawsuit Following a Residential Fire with a Natural Gas Explosion

When a gas explosion occurs in a home, analyzing evidence and determining the chain of events leading up to the explosion can be critical to resolving a lawsuit. If the provider is found to be at fault, injured parties can be awarded hundreds of thousands or even millions of dollars.

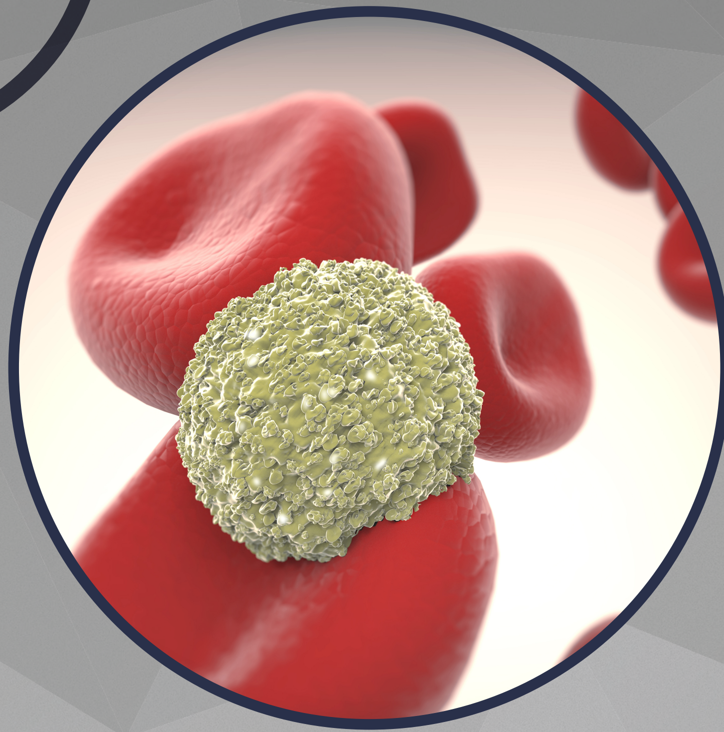
A natural gas company based in Western Canada was faced with legal action after a fire involving a natural gas explosion destroyed a home and damaged two others, resulting in one fatality and one injury. A three-quarter inch steel gas pipe that was 50 years old was found corroded and fractured at a kink where it passed through the concrete foundation. Was the fracture the cause or an effect of the explosion? How could one tell?

To perform an analysis, the company hired a forensic engineering firm, which in turn enlisted the Canadian Neutron Beam Centre to provide residual strain measurements. The strains at the point of fracture were found to be 'compressive' relative to a comparable pipe, meaning that the pipe would normally resist cracking. Yet a corrosion pit showed evidence of stress corrosion cracking, a type of cracking that is slow growing. These factors provided strong evidence that the pipe was likely subjected to tension over time while in service, and that the fracture was not due to faulty pipe. When the engineering firm inserted the strain data from the CNBC into computer models of how pipes fracture, this hypothesis was confirmed, thus eliminating one scenario in which the pipe fracture could have caused the fire.

The CNBC data provided strong evidence that the pipe was likely subjected to tension over time while in service, and that the fracture was not due to faulty pipe.

While the parties did not reach a final consensus about the root cause of the accident, the evidence from various sources—including the CNBC data—was valuable in informing them about the likelihood of whether the gas line was the cause or effect. Armed with this knowledge, the parties subsequently reached an out-of-court settlement.

PROBING MATERIALS FOR HEALTH



Aspirin Disrupts Cholesterol Rafts in Lipid Membranes

Fundamental research that uses neutron beams to investigate how our bodies work may lead to better health outcomes in the future by shedding light on our understanding of cholesterol and Aspirin.

Each of the trillions of cells in the human body has a lipid membrane that surrounds it. The existence of 'rafts' in cell membranes was hypothesized to explain a wide range of cellular functions. These rafts, conceptualized as tiny islands of order floating in oceans of less-orderly lipids, were believed to be induced by cholesterol. Their existence was debated for many years because observation of these small and short-lived rafts proved challenging. However, multiple direct experimental observations of these rafts have now been obtained using neutrons from the Canadian Neutron Beam Centre.

A research team, led by Professor Maikel Rheinstadter of McMaster University, is now building on these observations to learn about the role of cholesterol in these rafts, as well as how Aspirin affects them. The research team is using a combination of computer simulations and neutron diffraction at the CNBC to study controlled lipid membranes that model cell membranes.

*Regular strength enteric coated Aspirin tablets.

The team published recent findings in the top physics journal *Physical Review Letters*. They identified three structures involving cholesterol molecules in model membranes: (1) pairs of cholesterol molecules bound to each other and floating in the lipid outside the rafts; (2) rafts containing both lipid and cholesterol molecules forming an orderly pattern; and (3) cholesterol plaques.

The results illuminate how Aspirin disrupts the structures that cholesterol wants to create in the membranes.

The research team also examined the effects of adding Aspirin to these membranes. In addition to relieving headaches and fevers, Aspirin is known to increase positive outcomes for patients with high cholesterol; cholesterol stiffens membranes, while Aspirin loosens them. The exact mechanisms at play, however, were not fully understood.

Joining with Professor Thad Harroun's team at Brock University, the researchers used x-ray diffraction to show that Aspirin locally disrupts membrane organization, creating disorder that makes raft formation difficult. Then, using neutron diffraction, they examined the molecular organization of the lipids, cholesterol and Aspirin. The results show that the Aspirin molecules organize in a regular pattern throughout the membrane, with each Aspirin molecule associating with two lipid molecules.

Further, the rafts were no longer observed when Aspirin was added, confirming that the presence of Aspirin frustrates raft formation. These results add to a growing body ofevidence that Aspirin exerts its influence in membranes through non-specific interactions (as opposed to binding to the cholesterol, for example). These findings were published in 2015 in *Biochimica et Biophysica Acta (BBA) –Biomembranes*.

DOI:10.1103/PhysRevLett.113.228101
DOI:10.1016/j.bbamem.2014.11.023

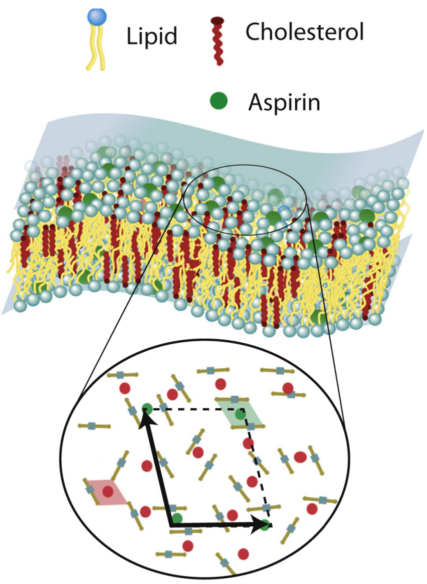


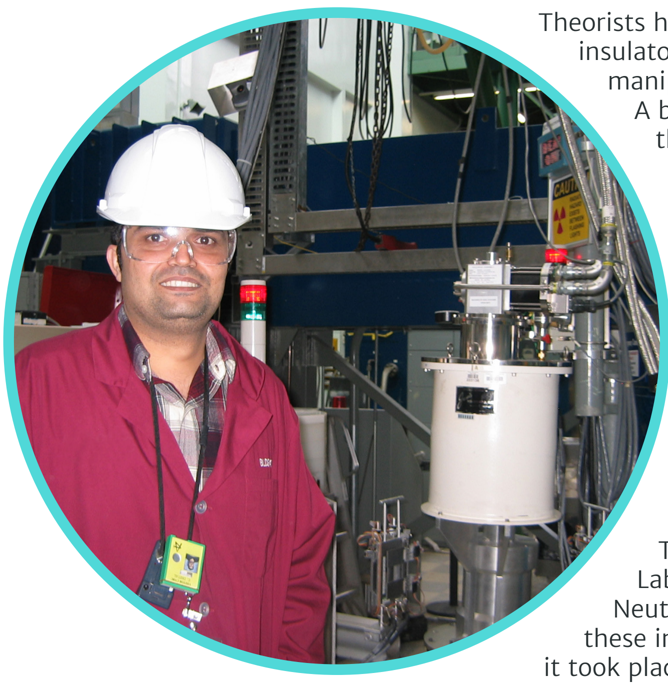
Illustration of a lipid bilayer containing cholesterol and Aspirin molecules in a super-lattice (black arrows). Different lipid environments are highlighted in green and red.

PROBING MATERIALS FOR **DISCOVERY**

Mapping the Behaviour of Charges in Correlated Spin-Orbit Coupled Materials

The findings, reported in Nature Communications, *confirm the properties that theorists predict could lead to discoveries in superconductivity, the topological phases of matter and new forms of magnetism.*

American physicists accessed the CNBC to map the inner atomic workings of a compound within a mysterious class of materials known as spin-orbit Mott insulators.



Boston College graduate student Chetan Dhital (pictured) gained hands-on experience at the N5 beamline while working under CNBC scientist Dr. Zahra Yamani to perform the experiments. Dr. Yamani also led the project to upgrade the detector's shielding.

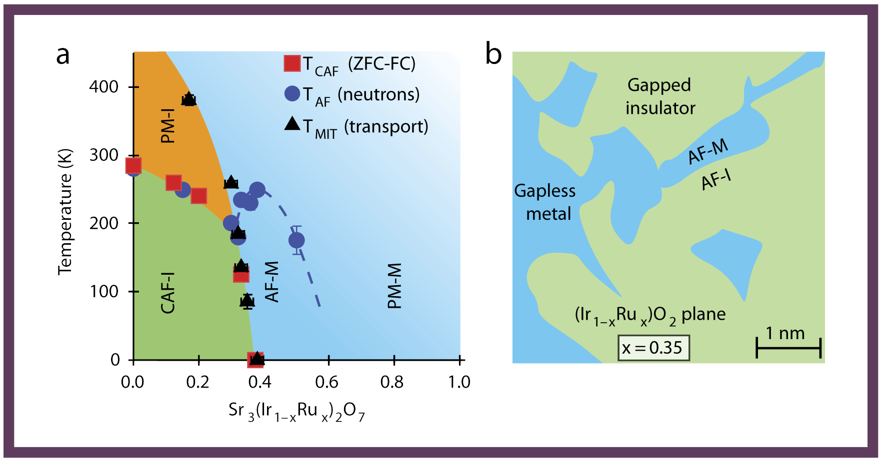
Theorists have predicted the emergence of new properties in spin-orbit Mott insulators, at points just beyond the insulating state, when electronic manipulation can transform these compounds into conducting metals. A better understanding of electrons near this transition could allow these new materials to pave the way to discoveries in superconductivity, new topological phases of matter and new forms of unusual magnetism. What scientists lacked until now was experimental evidence that reveals the microscopic mechanisms that actually drive one of these spin-orbit Mott insulators to become a metal.

A team of physicists led by Professor Stephen D. Wilson at Boston College (now at the University of California Santa Barbara) manipulated a compound of strontium, iridium and oxygen ($Sr_3Ir_2O_7$), successfully driving it into the metallic regime by replacing 40 percent of the iridium ions with ruthenium, thereby creating a metal alloy, $Sr_3(Ir_{1-x}Ru_x)_2O_7$.

The team, which included researchers from Oak Ridge National Laboratory, the NIST Center for Neutron Research and the Canadian Neutron Beam Centre, obtained a unique view into the workings of these insulators by mapping this previously uncharted transformation as it took place. The team created this map by combining scanning tunnelling microscopy and other techniques with neutron scattering to determine the electronic phase diagram of $Sr_3(Ir_{1-x}Ru_x)_2O_7$ in detail.

Neutron scattering experiments were performed at the CNBC's N5 triple-axis spectrometer to study how the antiferromagnetic order was affected by temperature and the amount of ruthenium ions. The N5 beamline was newly upgraded with improved shielding to increase the instrument's sensitivity. This upgrade was critical to the experiment because large single crystals of $Sr_3(Ir_{1-x}Ru_x)_2O_7$ are difficult to grow. In fact, the crystals were tiny, with dimensions of only about 2 x 2 x 0.1 mm and weighing only a few milligrams, and yet the upgraded instrument was sensitive enough to collect the required data.

Spin-orbit Mott insulators have complex electronic properties and are characterized by a delicate interplay between repulsive action and the coupling between electron spin and orbital motion. Specifically, the repulsive interaction between electrons tends to drive the electrons to a standstill. This tendency is bolstered by the lowering of the electron's energy via a strong interaction between the electron's magnetic field and its orbital motion around the nucleus.



(a) Electronic phase diagram of $Sr_3(Ir_{1-x}Ru_x)_2O_7$ as a function of ruthenium (Ru) concentration and temperature.
(b) Illustration of the basal plane showing phase-separated metallic puddles near the percolative threshold, which nucleate within the spin-orbit Mott insulating background of $Sr_3Ir_2O_7$.

Combining the data from all the techniques used, the team inferred that the ruthenium effectively created features within the compound that resembled minute metallic puddles. As the amount of additional ruthenium was increased, the puddles began to 'percolate,' coalescing to form a metal across which charges freely flowed.

In Prof. Wilson's words, "The addition of ruthenium introduces charge carriers, but at a low ratio of ruthenium to iridium they simply stay put in these little metallic puddles, which are symptoms of strongly correlated electrons. These electrons are stable and wouldn't move much. But when we stepped up the disruption by increasing the amount of ruthenium, the puddles moved together and achieved a metallic state."

Furthermore, according to Prof. Wilson, "The behavior in this particular compound parallels what researchers have seen in Mott insulators that play host to such phenomena as high temperature superconductivity. By pinpointing exactly where this transformation takes place, the team's findings should help to lay the groundwork in the scientific search for new electronic phases within spin-orbit Mott insulators."

This article has been adapted from ScienceDaily.com: http://www.sciencedaily.com/

DOI: 10.1038/ncomms4377

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 48 papers published in 2014, and 31 in 2015, may not be exhaustive.

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

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

2014

1. Biophysics at the Intersection of Health Science and Nuclear Technology. Drew Marquardt, Richard Alsop, Maikel Rheinstadterand Thad Harroun. Proceedings of the 3rd International Technical Meeting on Small Reactors. 2014 November 5-7. Canadian Nuclear Society. CNS Bulletin 35(4): 15 (2014).
2. Carrier localization and electronic phase separation in a doped spin-orbit-driven Mott phase in Sr3(Ir1−xRux)2O7. Chetan Dhital, Tom Hogan, Wenwen Zhou, Xiang Chen, Zhensong Ren, Mani Pokharel, Yoshinori Okada, M. Heine, Wei Tian, Z. Yamani, C. Opeil, J. S. Helton, J. W. Lynn, Ziqiang Wang, Vidya Madhavan, and Stephen D. Wilson. Nature Communications 5: 3377 (2014).
3. Characterization of Phase Transformations and Stresses During the Welding of a Ferritic Mild Steel. D. Dye, H.J. Stone, M. Watson, and R.B. Rogge. Metallurgical and Materials Transactions A: 2038 (45A) (2014).
4. Determining the Mechanism of In-Service Cylinder Distortion in Aluminum Engine Blocks with Cast-In Gray Iron Liners. Anthony Lombardi, Comondore Ravindran, Dimitry Sediako and Robert MacKay. Metallurgical and Materials Transactions A 45 (13): 6291-6303 (2014).
5. Dimyristoyl phosphatidylcholine: A remarkable exception to α-tocopherol's membrane presence. Drew Marquardt, Justin Williams, Jacob Kinnun, Norbert Kučerka, Jeffrey Atkinson, Stephen R. Wassall, John Katsaras, and Thad A. Harroun. Journal of the American Chemical Society 136: 202-210 (2014).
6. Effect of Chill Parameters on the Residual Strain in Cast 319 Aluminum Alloy: A Neutron Diffraction Study Vishank Kumar, Dimitry Sediako, and Lukas Bichler. SAE International Journal of Materials and Manufacturing. 7(2): 411-414 (2014). http://dx.doi.org/10.4271/2014-01-0836
7. Effects of N,N-dimethyl-N-alkylamine-N-oxides on DOPC bilayers in unilamellar vesicles: small-angle neutron scattering study. Michal Belicka, Norbert Kucerka, Daniela Uhrikova, Akhmed Kh. Islamov, Alexander I. Kuklin, Ferdinand Devinsky, and Pavol Balgavy. Eur Biophys J 43: 179–189 (2014).
8. Element-specific depth profile of magnetism and stoichiometry at the La0.67Sr0.33MnO3 / BiFeO3 interface. J. Bertinshaw, S. Brück, D. Lott, H. Fritzsche, Y. Khaydukov, O. Soltwedel, T. Keller, E. Goering, P. Audehm, D. L. Cortie, W. D. Hutchison, Q. M. Ramasse, M. Arredondo, R. Maran, V. Nagarajan, F. Klose, and C. Ulrich. Physical Review B 90: 041113-1-5 (2014).
9. Evolution of antiferromagnetic susceptibility under uniaxial pressure in Ba(Fe1-xCox)2As2. Chetan Dhital, Tom Hogan, Z. Yamani, Robert J. Birgeneau, W. Tian, M. Matsuda, A. S. Sefat, Ziqiang Wang, and Stephen D. Wilson. Phys. Rev. B 89: 214404 (2014).
10. Global small-angle X-ray scattering data analysis for multilamellar vesicles: the evolution of the scattering density profile model. P. Heftberger, B. Kollmitzer, F.A. Heberle, J. Pan, M. Rappolt, H. Amenitsch, N. Kučerka, J. Katsaras, and G. Pabst. Journal of Applied Crystalography 47: 173-170 (2014).
11. Hot tearing mechanisms of B206 aluminum–copper alloy. F. D'Elia, C. Ravindran, D. Sediako, K.U. Kainer, and N. Hort. Materials and Design 64: 44-55 (2014).
12. Identifying Further Inelastic Neutron Crystal Field Transitions in ErNiAl4. G.A. Stewart, W.D. Hutchison, Z. Yamani, J.M. Cadogan and D.H. Ryan. Proceedings of the 38th Annual Condensed Matter & Materials Meeting, Auckland (Waiheke Island), New Zealand, ISBN

9780646933399 (2014).
13. Intrinsic reduction of the ordered 4 f magnetic moments in semiconducting rare-earth nitride thin films: DyN, ErN, and HoN. D. L. Cortie, J. D. Brown, S. Brück, T. Saerbeck, J. P. Evans, H. Fritzsche, X. L. Wang, J. E. Downes, and F. Klose. Physical Review B 89: 064424 (2014).
14. In-situ neutron diffraction study of Zircaloy-4 subjected to biaxial tension. M.A. Gharghouri, D. McDonald, and L. Xiao. Proceedings of the 19th Pacific Basin Nuclear Conference, PBNC 2014-276 (2014).
15. Lipid Diversity and Its Implications for Membrane Organization. Jianjun Pan, Norbert Kučerka, Mu-Ping Nieh, Frederick A. Heberle, Paul Drazba, and John Katsaras. Liposomes, Lipid Bilayers and Model Membranes: 125 -142 (2014).
16. Liposomes, Lipid Bilayers and Model Membranes from Basic Research to Application. Edited by Georg Pabst, Norbert Kučerka, Mu-Ping Nieh, and John Katsaras. CRC Press 2014. Print ISBN: 978-1-4665-0709-8. eBook ISBN: 978-1-4665-0711-1
17. Liquid-like correlations in single-crystalline $Y_2Mo_2O_7$: An unconventional spin glass. H. J. Silverstein, K. Fritsch, F. Flicker, A. M. Hallas, J. S. Gardner, Y. Qiu, G. Ehlers, A. T. Savici, Z. Yamani, K. A. Ross, B. D. Gaulin, M. J. P. Gingras, J. A. M. Paddison, K. Foyevtsova, R. Valenti, F. Hawthorne, C. R. Wiebe, and H. D. Zhou. Phys. Rev. B 89: 054433 (2014).
18. Long-range magnetic order in the $5d^2$ double perovskite Ba_2CaOsO_6: Comparison with spin-disordered Ba_2YReO_6. Thompson, C.M., Carlo, J.P. , Flacau, R., Aharen, T., Leahy, I.A., Pollichemi, J.R., Munsie, T.J.S., Medina, T., Luke, G.M., Munevar, J., Cheung, S., Goko, T., Uemura, Y.J., Greedan, J.E. Journal of Physics: Condensed Matter 26: 306003 (2014). http://dx.doi.org/10.1088/0953-8984/26/30/306003
19. Magnetic structure of GdBiPt: A candidate antiferromagnetic topological insulator. Müller, R.A., Lee-Hone, N.R., Lapointe, L., Ryan, D.H., Pereg-Barnea, T., Bianchi, A.D., Mozharivskyj, Y., and Flacau, R. Phys. Rev. B 90: 041109 (2014).
20. Mechanical response of AZ31B magnesium alloy: Experimental characterization and material modeling considering proportional loading at room temperature. D. Ghaffari Tari, M. J. Worswick, U. Ali, and M. A. Gharghouri. International Journal of Plasticity 55: 247-267 (2014).
21. Micromechanical Behavior of Solid-Solution-Strengthened Mg-1wt.%Al Alloy Investigated by In-Situ Neutron Diffraction. Soo Yeol Lee, Wanchuck Woo, Michael A. Gharghouri, Cheol Yoon, and Ke An. Materials Science Forum 777: 130-135 (2014).
22. Non-Destructive Nuclear Forensics of Radioactive Samples. R.B. Rogge, Q. Alexander, G. Bentoumi, F. Dimayuga, R. Flacau, G. Li, L. Li, and B. Sur. ISBN 978-1-926773-16-2. Proceedings of the 19th Pacific Basin Nuclear Conference, PBNC 2014-310 (2014).
23. Partial Spin Ordering and Complex Magnetic Structure in $BaYFeO_4$: A Neutron Diffraction and High Temperature Susceptibility Study. C. M. Thompson, J. E. Greedan, V. O. Garlea, R. Flacau, M. Tan, P-H. T. Nguyen, F. Wrobel, and S. Derakhshan. Inorg. Chem. 53 (2): 1122 (2014).
24. Patterson analysis for layer profile determination by neutron or X-ray reflectometry. II. Zin Tun. J. Appl. Cryst. 47: 680–683 (2014).
25. Phonon density of states and anharmonicity of UO_2. Judy W. L. Pang, Aleksandr Chernatynskiy, Bennett C. Larson, William J. L. Buyers, Douglas L. Abernathy, Kenneth J. McClellan, and Simon R. Phillpot. Physical Review B 89: 115132 (2014).
26. Platinum Uptake and Ba_2CePtO_6 Formation During in Situ $BaCe_{1-x}M_x O_{3-\delta}$ (M = La, In) Formation. Lussier, J.A., Shafi, S.P., Donaberger, R.L.; Bieringer, M. Inorganic Chemistry, 2014, 53, 8809–8815. http://pubs.acs.org/doi/abs/10.1021/ic501510u
27. Pressure-induced changes on the electronic structure and electron topology in the direct FCC to SH transformation of silicon. Tse, J.S., Hanfland, M., Flacau, R., Desgreniers, S., Li, Z., Mende, K., Gilmore, K., Nyrow, A., Moretti Sala, M., Sternemann C. Journal of Physical Chemistry C 118: 1161 (2014)
28. Probing the Hydration of Ultrathin Antifouling Organosilane Adlayers using Neutron Reflectometry. Natalia M. Pawlowska, Helmut Fritzsche, Christophe Blaszykowski, Sonia Sheikh, Mansoor Vezvaie and Michael Thompson. Langmuir 30: 1199-1203 (2014). http://dx.doi.org/10.1021/la4038233
29. Quantification of Residual Strain Associated with Reduction of Hot Tears by Grain Refinement in B206 Aluminum Alloy. F. D'Elia, C. Ravindran, and D. Sediako. Canadian Metallurgical Quarterly 53 (2): 151-159 (2014).
30. Residual Stress Mapping along the Cylinder Bores of Al Alloy Engine Blocks Subjected to Production Solution Heat Treatment Schedule. Anthony Lombardi, Dimitry Sediako, C. (Ravi) Ravindran, and Robert Mackay. SAE International Journal of Materials and Manufacturing 7(2): 415-420 (2014). http://dx.doi.org/10.4271/2014-01-0837
31. Stress Analysis of Feeder Bends Using Neutrons: New Results and Cumulative Impacts. D. Banks, R. Donaberger, B. Leitch and R. Rogge. ISBN 978-1-926773-16-2. Proceedings of the 19th Pacific Basin Nuclear Conference, PBNC 2014-186 (2014).
32. Strict limit on in-plane ordered magnetic dipole moment in URu_2Si_2. K. A. Ross, L. Harriger, Z. Yamani, W. J. L. Buyers, J. D. Garrett, A. A. Menovsky, J. A. Mydosh, and C. L. Broholm. Physical Review B 89: 155122 (2014).
33. Structural and magnetic behavior of the cubic oxyfluoride $SrFeO_2F$ studied by neutron diffraction. Corey M. Thompson, Colin K. Blakely, Roxana Flacau, John E. Greedan, and Viktor V. Poltavets. Journal of Solid State Chemistry 219: 173–178 (2014).
34. Structure of Cholesterol in Lipid Rafts. Laura Toppozini, Sebastian Meinhardt, Clare L. Armstrong, Zahra Yamani, Norbert Kučerka, Friederike Schmid, and Maikel C. Rheinstädter. Phys. Rev. Lett. 113: 228101 (2014).
35. Surface twist instabilities and skyrmion states in chiral ferromagnets. S. A. Meynell, M. N. Wilson, H. Fritzsche, A. N. Bogdanov, and T. L. Monchesky. Physical Review B 90: 014406 (2014).
36. Synthesis, structure and magnetic properties of $(Tb_{1-x}Mn_y)MnO_{3-\delta}$. Hao Zhang, Roxana Flacau, Junliang Sun, Guobao Li, Fuhui Liao, and Jianhua Lin. Inorg. Chem. 53(9): 4535 (2014).
37. The investigation of the triaxial residual stress in the friction stir welded lap joint using neutron diffraction. Michael Bach, Ali Merati, Michael Gharghouri, Ronald Rogge, Robert Bell, Xin Wang. Materials Science Forum 768-769: 589-596 (2014).
38. The molecular structure of a phosphatidylserine bilayer determined by scattering and molecular dynamics simulations. Jianjun Pan, Xiaolin Cheng, Luca Monticelli, Frederick A. Heberle, Norbert Kucerka, D. Peter Tielemanh and John Katsaras. Soft Matter 10: 3716–3725 (2014).
39. The Penetration Depth of Chemical Reactions in a Thin-Film Co_3O_4 Supercapacitor Electrode. M. Vezvaie, P. Kalisvaart, H. Fritzsche, Z. Tun and D. Mitlin. Journal of The Electrochemical Society 161 (5): A798-A802 (2014).
40. The sensitivity of neutron scattering to hydrogen in nuclear fuel. M.A. Gharghouri, R. Donaberger, N. Wang, S. Hibbins. Proceedings of the 19th Pacific Basin Nuclear Conference, PBNC 2014-274 (2014).
41. Thermal Neutron Scattering Cross

Section Measurements of Light and Heavy Water. G. Li, G. Bentoumi, Z. Tun, L. Li and B. Sur. Proceedings of 34rd Annual Conference of the Canadian Nuclear Society & 37th CNS/CNA Student Conference, Toronto, June 2013. Curran Assoc. Inc.: 88-89 (2014).

42. Using Monte Carlo ray tracing simulations to model the quantum harmonic oscillator modes observed in uranium nitride. J. Y. Y. Lin, A. A. Aczel, D. L. Abernathy, S. E. Nagler, W. J. L. Buyers, and G. E. Granroth. Phys. Rev. B 89: 144302 (2014).
43. Structural transformations in R3Cu4Sn4 (R=Ho, Er, Tm) intermetallic compounds. J.M. Cadogan, S. Muñoz Pérez, R. Cobas, D.H. Ryan, R. Lora-Serrano, M.J.S. Figueira and F. Yokaichiya. Intermetallics 55: 123-128 (2014).
44. Neutron powder diffraction and Mössbauer spectroscopy (119Sn and 155Gd) studies of the CeScSi-type GdMgSn and GdMgPb compounds. P. Lemoine, N. R. Lee-Hone, D. H. Ryan, A. Vernière, B. Malaman, and G. Le Caër. Phys. Rev. B 89: 174428(9) (2014).
45. Spin reorientation in GdGa. R.A. Susilo, J.M. Cadogan, D.H. Ryan, N.R. Lee-Hone, R. Cobas and S. Muñoz Pérez. Hyp. Int. 226: 257-266 (2014).
46. On the magnetic order of Gd5Ge3. J.M. Cadogan, D.H. Ryan, and Ya. Mudryk, V.K. Pecharsky and K.A. Gschneidner Jr. J. Appl. Phys. 115: 17A901(3) (2014).
47. Thermal neutron diffraction determination of the magnetic structure of EuCu2Ge2. W.N. Rowan-Weetaluktuk, P. Lemoine, J.M. Cadogan and D.H. Ryan. J. Appl. Phys. 115: 17E101(3) (2014).
48. Magnetic structure of the high temperature superconductor Gd1-xThx-FeAsO. N.R. Lee-Hone, D.H. Ryan, J.M. Cadogan, Y.L. Sun and G.-H. Cao. J. Appl. Phys. 115: 17D705(3) (2014).

2015

1. Characterization of the microstructure, mechanical properties, and shot peening response of an industrially processed Al–Zn–Mg–Cu alloy. Harding, M.D., Donaldson, I.W., Hexemer Jr., R.L., Gharghouri, M.A., and Bishop, D.P. Journal of Materials Processing Technology. 221: 31-39 (2015).
2. Evaluation of elastic–viscoplastic self-consistent polycrystal plasticity models for zirconium alloys. H. Qiao, P.D. Wu, H. Wang, M.A. Gharghouri, and M.R. Daymond. International Journal of Solids and Structures. 71: 308-322 (2015).
3. Improving Microstructure and Ductility in the Mg-Zn Alloy System by Combinational Ce-Ca Microalloying. B. Langelier, A.M. Nasiri, S.Y. Lee, M.A. Gharghouri, and S. Esmaeili. Materials Science and Engineering A, 620: 76-84 (2015).
4. In-situ Study of Microstructure Evolution in Solidification of Hypereutectic Al-Si Alloys with Application of Thermal Analysis and Neutron Diffraction. D. Sediako and W. Kasprzak. Metallurgical and Materials Transactions A: 46(A): 4160-4173 (2015). http://link.springer.com/article/10.1007/s11661-015-3007-0
5. Interplay Among Solidification, Microstructure, Residual Strain and Hot Tearing in B206 Aluminum Alloy. F. D'Elia, C. Ravindran, and D. Sedia-ko. Materials Science & Engineering A, 624: 169–180 (2015). http://dx.doi.org/10.1016/j.msea.2014.11.057
6. Investigation of Solidification Behaviour of Mg–6Al and Mg–9Al Alloys Using in situ Neutron Diffraction. A. Elsayed, D. Sediako, and C. Ravindran. Canadian Metallurgical Quarterly 54(1): 16-23 (2015). http://dx.doi.org/10.1179/1879139514Y.0000000159
7. Investigations on the Stress and Strain Evolution in AZ91D Magnesium Alloy Castings During Hot Tearing. L. Bichler, and C. Ravindran. Journal of Materials Engineering and Performance 24(6): 2208–2218 (2015). http://dx.doi.org/10.1007/s11665-015-1454-9
8. Solidification Analysis of Al–5 wt-%Cu Alloy Using in situ Neutron Diffraction. F. D'Elia, C. Ravindran, D. Sediako, and R. Donaberger. Canadian Metallurgical Quarterly 54(1): 9-15 (2015). http://dx.doi.org/10.1179/1879139514Y.0000000158
9. Solidification Behavior of Mg-Zn and Mg-Zn-Zr Alloys Using In-Situ Neutron Diffraction. A. Elsayed, D. Sediako and C. Ravindran. Journal of Materials Engineering and Performance 24(6): 2250-2255 (2015). ISSN: 1544-1024. http://dx.doi.org/10.1007/s11665-015-1497-y
10. Twinning-Detwinning Behavior during Cyclic Deformation of Magnesium Alloy. Lee, Soo Yeol, Wang, Huamaio, and Gharghouri, M.A. Metals, 5: 881-890 (2015).
11. First-Order Melting of a Weak Spin-Orbit Mott Insulator into a Correlated Metal. T. Hogan, Z. Yamani, D. Walkup, Xiang Chen, Rebecca Dally, Thomas Z. Ward, M.P.M. Dean, John Hill, Z. Islam, Vidya Madhavan, and Stephen D. Wilson. Phys. Rev. Lett. 114: 257203 (2015). http://dx.doi.org/10.1103/PhysRevLett.114.257203
12. Frustrated fcc antiferromagnet Ba2YOsO6: Structural characterization, magnetic properties, and neutron scattering studies. E. Kermarrec, C. A. Marjerrison, C. M. Thompson, D. D. Maharaj, K. Levin, S. Kroeker, G. E. Granroth, R. Flacau, Z. Yamani, J. E. Greedan, and B. D. Gaulin. Phys. Rev. B 91: 075133 (2015). http://dx.doi.org/10.1103/PhysRevB.91.075133
13. Structural and Magnetic Phase Transitions near Optimal Superconductivity in BaFe2(As1-xPx)2. Ding Hu, Xingye Lu, Wenliang Zhang, Huiqian Luo, Shiliang Li, Peipei Wang, Genfu Chen, Fei Han, Shree R. Banjara, A. Sapkota, A. Kreyssig, A.I. Goldman, Z. Yamani, Christof Niedermayer, Markos Skoulatos, Robert Georgii, T. Keller, Pengshuai Wang, Weiqiang Yu, and Pengcheng Dai. Phys. Rev. Lett. 114: 157002 (2015). http://dx.doi.org/10.1103/PhysRevLett.114.157002
14. Separation of magnetic and superconducting behavior in YBa2Cu3O6.33 (Tc = 8.4K). Zahra Yamani, W. J. L. Buyers, F. Wang, Y.-J. Kim, J.-H. Chung, S. Chang, P. M. Gehring, G. Gasparovic, C. Stock, C. L. Broholm, J. C. Baglo, Ruixing Liang, D. A. Bonn, and W. N. Hardy. Phys. Rev. B: 91: 134427 (2015). http://dx.doi.org/10.1103/PhysRevB.91.134427
15. Magnetic structure of the antiferromagnetic half-Heusler compound NdBiPt. R. A. Müller, A. Desilets-Benoit, N. Gauthier, L. Lapointe, A. D. Bianchi, T. Maris, R. Zahn, R. Beyer, E. Green, J. Wosnitza, Z. Yamani, and M. Kenzelmann. Phys. Rev. B 92: 184432 (2015).
16. Mott-Kondo insulator behavior in the iron oxychalcogenides. B. Freelon, Yu Hao Liu, Jeng-Lung Chen, L. Craco, M. S. Laad, S. Leoni, Jiaqi Chen, Li Tao, Hangdong Wang, R. Flauca, Z. Yamani, Minghu Fang, Chinglin Chang, J.-H. Guo, and Z. Hussain. Phys. Rev. B 92: 155139 (2015). http://dx.doi.org/10.1103/PhysRevB.92.155139
17. Aspirin inhibits formation of cholesterol rafts in fluid lipid membranes. Richard J. Alsop, Laura Toppozini, Drew Marquardt, Norbert Kučerka, Thad A. Harroun, and Maikel C. Rheinstädter. BBA-Biomembranes 1848: 805-812 (2015). http://dx.doi.org/10.1016/j.bbamem.2014.11.023
18. In-situ Temperature-controllable Shear Flow Device for Neutron Scattering measurement—An example of aligned bicellar mixtures. Yan Xia, Ming Li, Norbert Kučerka, Shutao Li, and Mu-Ping Nieh. Review of Scientific Instruments 86: 025112 (2015). http://dx.doi.org/10.1063/1.4908165
19. Tocopherol's location in membranes

is not affected by their composition. Drew Marquardt, Norbert Kučerka, John Katsaras, and Thad A. Harroun. Langmuir 31(15): 4464-4472 (2015). http://dx.doi.org/10.1021/la502605c

20. α-Tocopherol Is Well Designed to Protect Polyunsaturated Phospholipids: MD Simulations. Xiaoling Leng, Jacob J. Kinnun, Drew Marquardt, Mikel Ghefli, Norbert Kucerka, John Katsaras, Jeffrey Atkinson, Thad A. Harroun, Scott E. Feller, and Stephen R. Wassall, Biophysical Journal 109(8): 1608-1618 (2015). ISSN 0006-3495. http://dx.doi.org/10.1016/j.bpj.2015.08.032
21. Cation exchange mediated elimination of the Fe-antisites in the hydrothermal synthesis of LiFePO4. Andrea Paolella, Giovanni Bertoni, Pierre Hovington, Zimin Feng, Roxana Flacau, Mirko Prato, Massimo Colombo, Sergio Marras, Liberato Manna, Stuart Turner, Gustaaf Van Tendeloo, Abdelbast Guerfi, George P. Demopoulos, and Karim Zaghib. Nano Energy 16: 256–267 (2015). http://dx.doi.org/10.1016/j.nanoen.2015.06.005
22. In-situ powder diffraction on TiF3 catalysed magnesium for hydrogen storage applications. R. Flacau, X. Tan, M. Danaie, H. Fritzsche, and D. Mitlin. Can. Met. Quarterly 54: 47-50 (2015).
23. From soft harmonic phonons to fast relaxational dynamics in CH3NH3PbBr3. I.P. Swainson, C. Stock, S. F. Parker, L. Van Eijck, M. Russina, and J. W. Taylor. Physical Review B 92: 100303(R) (2015).
24. Synthesis, structure, and magnetic properties of novel B-site ordered double perovskites, SrLaMReO6 (M = Mg, Mn, Co and Ni). C.M. Thompson, L. Chi, J.R.R. Hayes, A.M. Hallas, M.N. Wilson, T.J.S. Munsie, I.P. Swainson, A.P. Grosvenor, G.M. Luke, J.E. Greedan. Dalton Transactions 44(23): 10806-10816 (2015).
25. Interdiffusion of Fe and Mg layers during annealing and deuterium absorption. H. Fritzsche, S. Bilodeau, R. Flacau, P. Jain, J. Huot, P. Kalisvaart, and D. Mitlin. Can. Met. Quarterly 54: 43-46 (2015).
26. Reactions in a multilayered Si (substrate)/Ta/Mg/Fe/Ta/Pd thin-film structure during annealing and deuterium absorption. M. Danaie, H. Fritzsche, W. P. Kalisvaart, X. Tan, D. Mitlin, G. A. Botton, and J. Huot. Acta Mater. 90: 259-271 (2015).
27. Water uptake and swelling hysteresis in a nafion thin film measured with neutron reflectometry. W. P. Kalisvaart, H. Fritzsche, and W. Mérida. Langmuir 31: 5416-5422 (2015).
28. In situ Neutron Diffraction Analysis of Stress-free d-spacing During Solution Heat Treatment of Modified 319 Al Alloy Engine Blocks. A. Lombardi, D. Sediako, C. Ravindran, and R. MacKay. Canadian Metallurgical Quarterly 54(1): 30-37 (2015). http://dx.doi.org/10.1179/1879139514Y.0000000161
29. Transient Analysis of Residual Strain during Heat Treatment of Multi-material Engine Blocks using In-situ Neutron Diffraction. Lombardi, A., Sediako, D., Machin, A., Ravindran, C., and MacKay, R. Materials Letters 157: 50-52 (2015).
30. Non-Destructive Examination Using Neutrons: A Nuclear Waste And Orphaned Source Characterization Case Study Applicable To Nuclear Forensics. Ronald B. Rogge, Ghaouti Bentoumi, F. (Ike) Dimayuga, Roxana Flacau, Gang Li, Liqian Li, and Bhaskar Sur. CNL Nuclear Review 4(2): 141-154 (2015).
31. Quantum Phase Transitions. Sara Haravifard, Zahra Yamani, Bruce D. Gaulin. Neutron Scattering, Magnetic and Quantum Phenomena. Experimental Methods in the Physical Sciences. 48: 43–144 (2015)