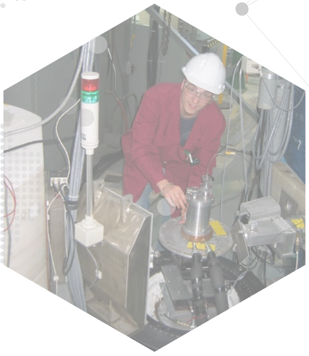
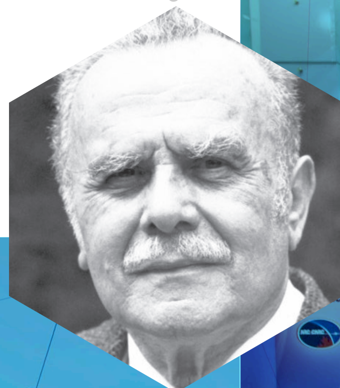
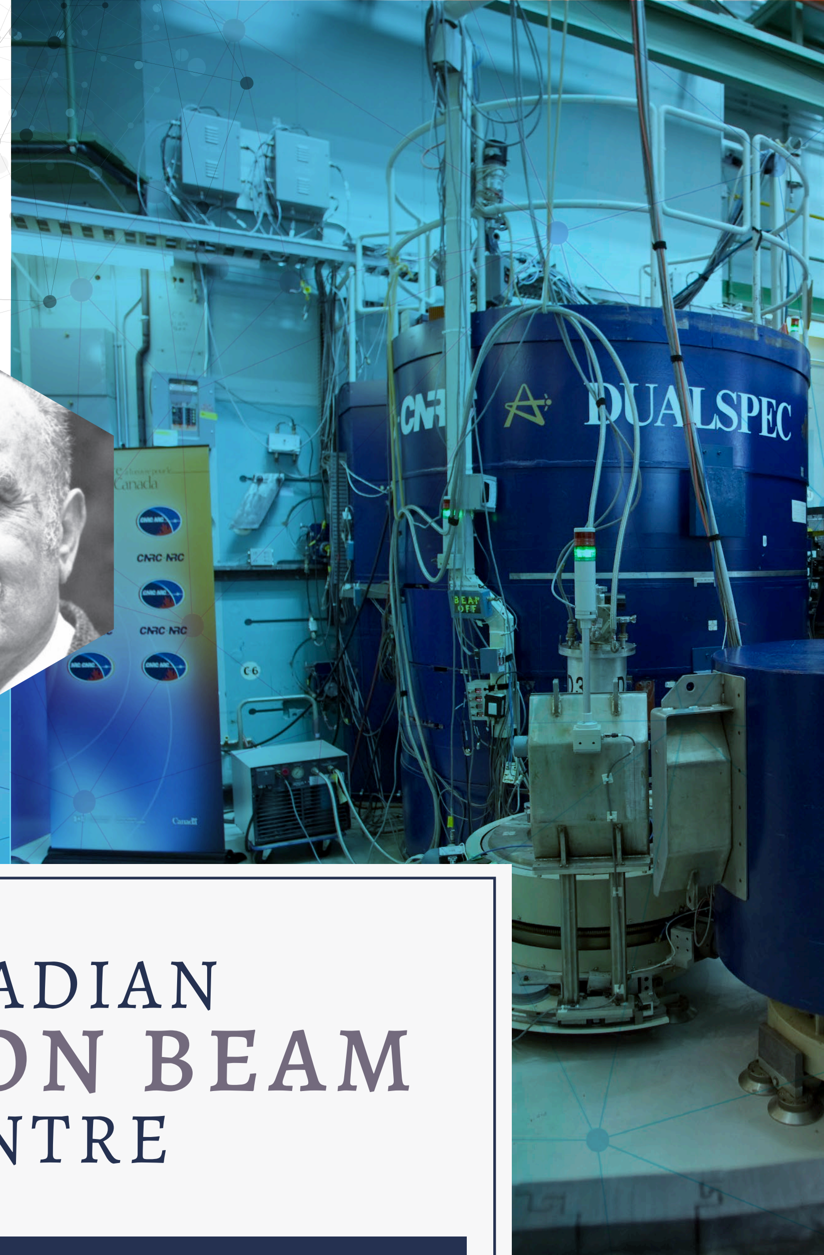






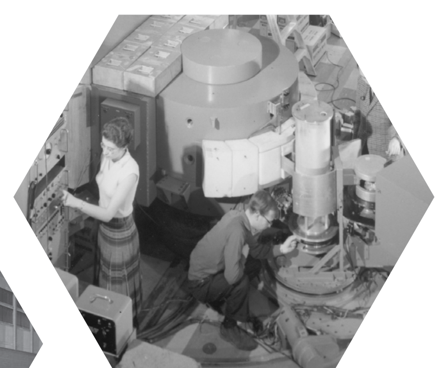
OVER
2,300
RESEARCH PUBLICATIONS

70%
ABOVE WORLD AVERAGE IN HIGHLY CITED PAPERS

787
PARTICIPATING RESEARCHERS

CANADIAN NEUTRON BEAM CENTRE

FINAL ACTIVITY REPORT



2019

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

CANADIAN NEUTRON BEAM CENTRE
Probing Materials for Science and Industry

PROBING MATERIALS FOR SCIENCE AND INDUSTRY

BRITISH COLUMBIA
SIMON FRASER
UBC OKANAGAN
ALBERTA
CALGARY
SASKATCHEWAN
MANITOBA
WINNIPEG
WINDSOR
WESTERN
GUELPH
WATERLOO
MCMASTER
TORONTO
RYERSON
BROCK
TRENT
ROYAL MILITARY COLLEGE
QUEEN'S
OTTAWA
CARLETON
MCGILL
MONTRÉAL
CONCORDIA
POLYTECHNIQUE MONTRÉAL
ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
SHERBROOKE
QUÉBEC À TROIS-RIVIÈRES
ST. FRANCIS XAVIER
DALHOUSIE

The specialized facilities and expertise of the Canadian Neutron Beam Centre supported industry innovation and served as a resource for Canadians to train and work at the leading edge of science and technology. Over a five-year period, CNBC research participants typically included more than 700 individuals from over 60 departments in about 30 Canadian universities, and from over 100 foreign institutions in over 20 countries.

Canadian Neutron Beam Centre
Activity Report to the
Canadian Institute for Neutron Scattering
for 2016 to 2018

Disponsible en français

70 YEARS

of neutron beams for materials research

Canada has been a global leader in the use of neutron beams for materials research for over 70 years. Our leadership began with the start-up of the NRX reactor at Chalk River Laboratories in 1947 and continued with the operation of the NRU reactor, which went into service a decade later. This proud heritage spans from the pioneering days of developing neutron scattering techniques through to the global recognition of neutron beams as an invaluable tool for the study of materials. The importance of these advancements was marked by the 1994 Nobel Prize in Physics, as well as by the proliferation of neutron beam facilities around the world.

Today, we are proud to have grown a strong Canadian community of neutron beam users who have engaged with us to maximize value from our beamlines until the very last moment of the NRU reactor's operating life in March 2018. While the full impact of the most recent experiments will be revealed in the coming years, there is plenty to celebrate now. In this report, we present numerous facts, figures, testimonies, and highlights that demonstrate why we are so proud to have sustained high-quality science and engineering research for more than 70 years.

JOHN ROOT
DIRECTOR OF THE CANADIAN NEUTRON BEAM CENTRE

The DUALSPEC instrument included two neutron beamlines that were highly subscribed by scientists and engineers for solving the atomic structures of new or modified materials, as well as for studying magnetism and atomic motions in quantum materials.

MILESTONES

1947 | PG. 30

The National Research Council completed the National Research Experimental (NRX) reactor

1949 | PG. 30

The first paper using neutron scattering was published by Norman Alcock and Don Hurst; it reported diffraction from oxygen and carbon dioxide gases

1952 | PG. 30

The National Research Council spun off Atomic Energy of Canada, Ltd. (AECL) to promote the peaceful use of nuclear energy

1953 | PG. 30

Dave Henshaw and Don Hurst reported the first measurements on the structure of liquid helium; such studies illuminated global understanding of the quantum properties of materials

1955 | PG. 30

Bertram Brockhouse and Alec Stewart published the first demonstration of inelastic neutron scattering, one of Brockhouse's pioneering accomplishments that led to his Nobel Prize in Physics nearly four decades later

1957 | PG. 31

The National Research Universal (NRU) reactor was completed

1960 | PG. 31

Neutron Physics became a separate branch of AECL

1961-1965 | PG. 31

A new generation of scientists joined the Neutron Physics Branch and maintained its world leadership

1971 | PG. 31

The Neutron Physics Branch became the Neutron and Solid State Physics Branch

1980-1982 | PG. 31

Eric Svensson, Varley Sears, Dave Woods, and Peter Martel reported key measurements of the quantum mechanical properties of low-temperature liquid helium

1983 | PG. 32

Tom Holden, with Brian Powell and Gerald Dolling, demonstrated neutron stress scanning for industrial components

CONTINUED ON NEXT PAGE

MILESTONES

1985 | PG. 33

- Bill Buyers performed a ground-breaking experiment that provided evidence for a new class of materials, called topological materials
- Funding awarded for the construction of the DUALSPEC facility, which included two beamlines, marked the beginning of the formal user program

1986 | PG. 33

The Canadian Institute for Neutron Scattering was incorporated to maximize access to DUALSPEC and to represent the interests of the growing neutron beam user community

Tom Holden and John Root used neutron stress scanning to aid the investigation into the Space Shuttle Challenger disaster

1992 | PG. 33

- DUALSPEC began operations
- The Neutron and Solid State Physics Branch became the Neutron and Condensed Matter Science Branch
- Varley Sears published the authoritative tables of neutron scattering lengths and cross-sections, which are still in use today

1993 | PG. 33

The NRX reactor closed permanently

1994 | PG. 34

- Bertram Brockhouse was awarded the Nobel Prize in Physics
- Neutron imaging at Chalk River was spun off as a private business, NRay Services Inc., which still serves the aerospace industry by providing quality inspections of turbine blades

1997 | PG. 35

The neutron beam laboratory was transferred to the National Research Council

2001 | PG. 36

NSERC awarded operating funding for the entire neutron beam laboratory, not just DUALSPEC, to maintain a state of readiness for academic user access

2001 - 2011 | PG. 36

Neutron stress scanning of nuclear power plant components made major impacts on the industry

2004 | PG. 36

Funding was awarded to build the D3 neutron reflectometer

CONTINUED ON NEXT PAGE

MILESTONES

2005 | PG.36

The neutron beam laboratory was renamed the Canadian Neutron Beam Centre (CNBC) to reflect the national user facility mission

2007 | PG. 36

The D3 neutron reflectometer opened as a user facility

2013 | PG. 37

AECL resumed funding and operations of the CNBC due to changing mandates at both AECL and the National Research Council

2015 | PG. 37

The Government of Canada announced the closure of the NRU reactor, effective March 2018

2016 | PG. 37

The Nobel Prize in Physics recognized the importance of the discovery of topological materials

2018 | PG. 37

The NRU reactor generated its last neutrons and ceased operations on March 31, 2018

CNBC BY THE NUMBERS

SCIENTIFIC EXCELLENCE

210
RESEARCH PUBLICATIONS

2013 — 5 YEARS — 2017

OVER
2,300
RESEARCH PUBLICATIONS

JULY 1947 — LIFETIME — MARCH 2018

The full publication list is available at: cins.ca/resources/cnbc

SINCE 2000

70%
ABOVE WORLD AVERAGE IN HIGHLY CITED PAPERS

The CNBC's share of the 10% most highly cited papers in the world since 2000, normalized by year and scientific subfield, was 17%.

The CNBC's Average of Relative Citations (ARC) from all papers since 2000, normalized by year and scientific subfield was 1.39.

40%
ABOVE WORLD AVERAGE IN CITATIONS

60%
ABOVE WORLD AVERAGE IN CITATIONS, FOR INTERNATIONAL COLLABORATIONS

The CNBC's Average of Relative Citations (ARC) from papers with at least one foreign co-author since 2000, normalized by year and scientific subfield was 1.58.

Source: Science-Metrix. "Bibliometric study on CNBC's scientific publications 1980-2017" (Sep 2018) Available from: http://cins.ca/resources/cnbc/

"The CNBC's performance between 1980 and 2017 can be described as a steady output of papers of a high quality that incrementally improved over time."

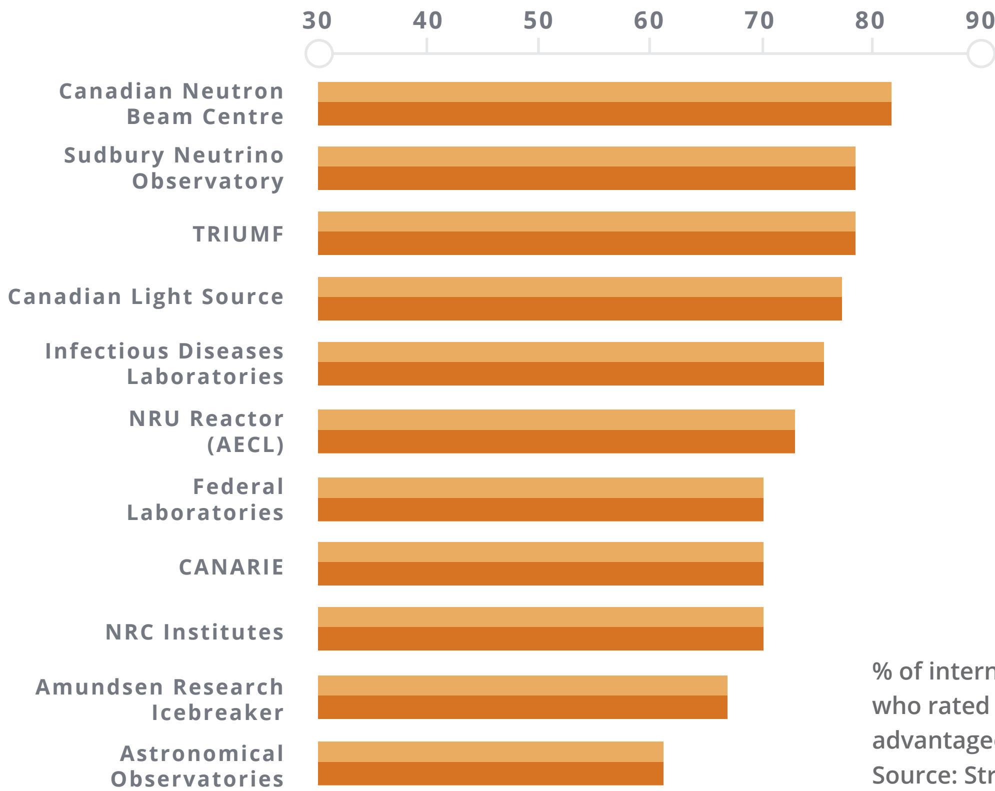
– Science-Metrix

SINCE 2001

2.3X
MORE CANADA RESEARCH CHAIRS (CRCS) THAN NATIONAL AVERAGE

The fraction of professors in the CNBC's user community who hold or have held CRCs since 2001 is 2.3 times greater than the same fraction of all professors funded by NSERC. Source: Strapolec. "Study of CNBC Performance and Impacts" (Feb 2019) Available from: http://cins.ca/resources/cnbc/

TOP INTERNATIONAL REPUTATION



% of international scientists who rated each facility as advantageous to Canada in 2006.
Source: Strapolec (CCA 2006 data)

NATIONAL AND GLOBAL USER COMMUNITY

787 PARTICIPATING RESEARCHERS — 5 YEARS

4,000 EST PARTICIPATING RESEARCHERS — LIFETIME

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 that year. This is a standardized measure for North American neutron facilities. A user is defined as an individual who visited the CNBC to conduct an experiment, or who is a co-proposer of an experiment that used beam time.

5 YEARS

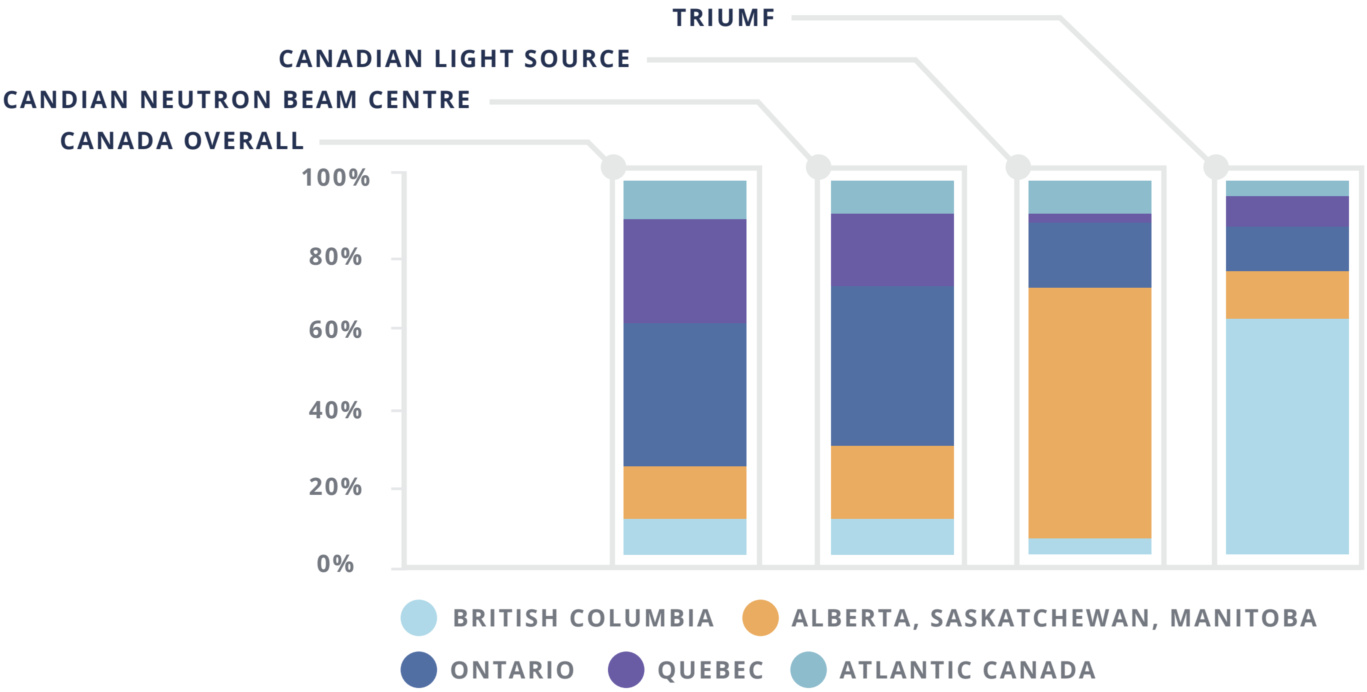
358
Canadian university researchers

125
Industry or Canadian government researchers

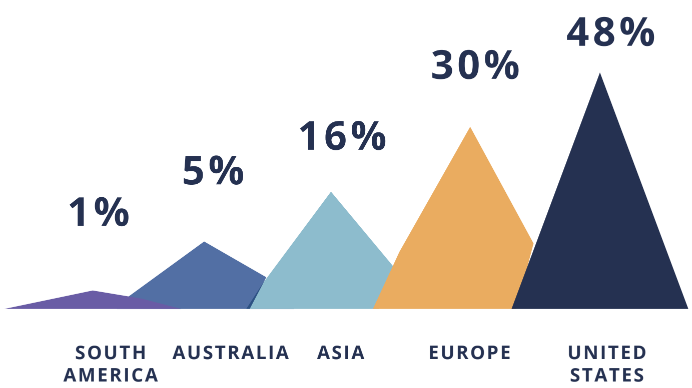
64
University departments from 28 Canadian universities in 7 provinces

429
researchers from 139 foreign institutions in 22 countries

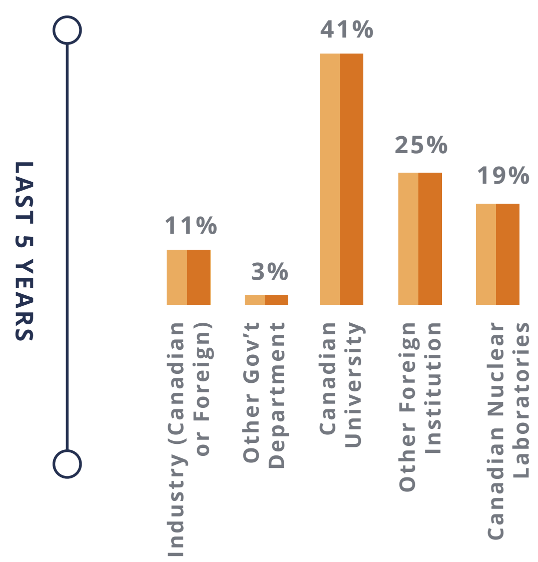
MOST NATIONALLY DISTRIBUTED USER COMMUNITY



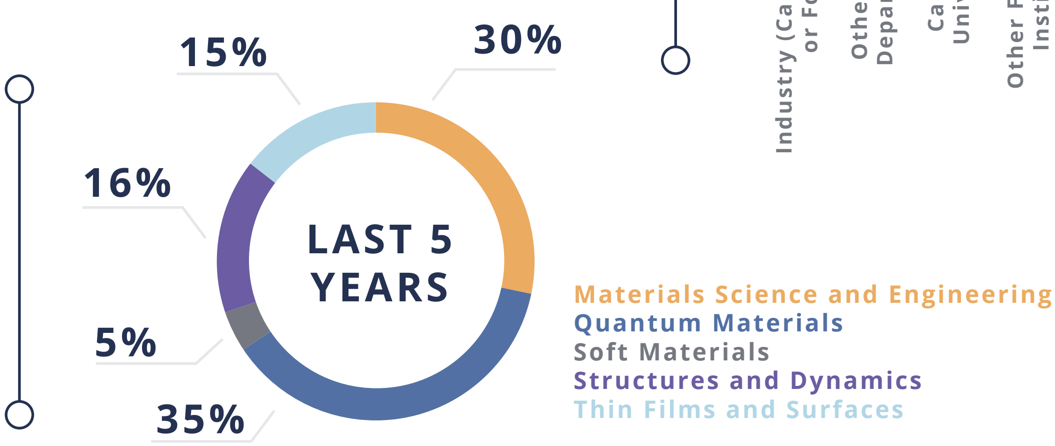
FOREIGN RESEARCH PARTICIPANTS



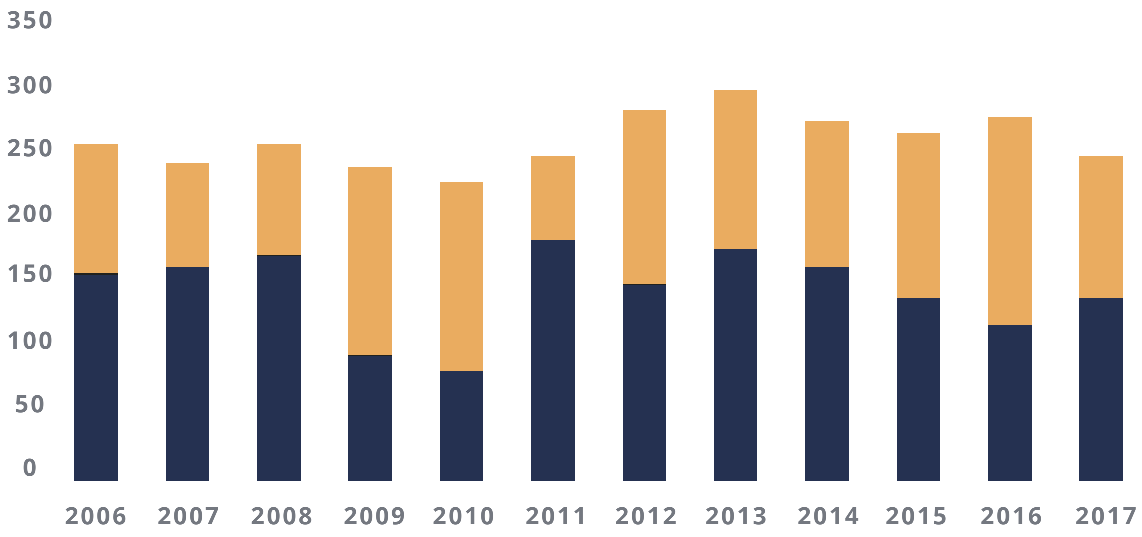
USER BEAM TIME BY USER SECTOR



USER BEAM TIME BY SUBJECT AREA



RESEARCH PARTICIPANTS



The user community has remained highly engaged with the CNBC over time. Research participants in the CNBC include users and their co-authors on publications. Note: The neutron source was shut down for 15 months in 2009–2010.

USERS CO-AUTHORS

ENGAGEMENT WITH INDUSTRY

SINCE 2001

4 X

MORE INDUSTRIAL RESEARCH CHAIRS (IRCS) THAN NATIONAL AVERAGE

The fraction of professors in the CNBC's user community who hold or have held IRCs since 2001 is four times greater than the same fraction of all professors funded by NSERC. Source: Strapolec

$$$ 3 X

MORE HOLDERS OF COLLABORATIVE R&D (CRD) GRANTS THAN NATIONAL AVERAGE

The fraction of professors in the CNBC's user community who have received CRD grants since 2001 is three times greater than the same fraction of all professors funded by NSERC. Source: Strapolec

SINCE 1983

231

proprietary research reports for industry

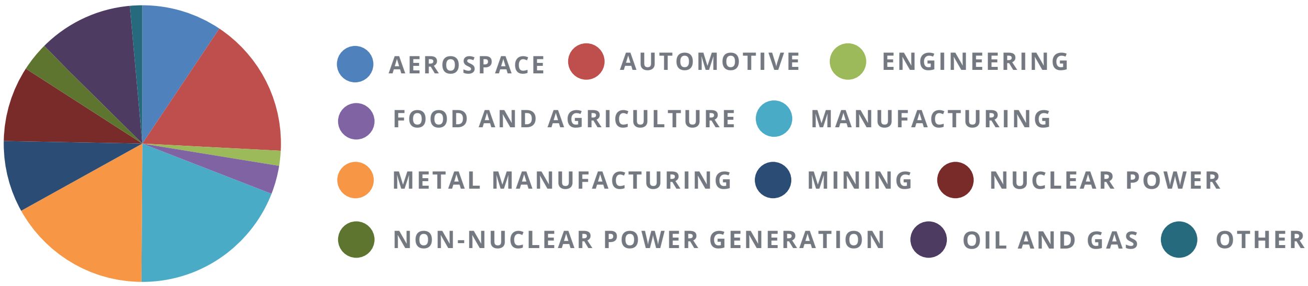
SINCE 2001

40%

higher industry matching funds than the national average

Professors in the CNBC's user community have received 14.2% of their funding from industry over average since 2001, compared to 10% in the case of all professors funded by NSERC. Source: Strapolec

DIVERSE DISTRIBUTION OF INDUSTRY SPONSORSHIP OF USERS



FACILITY OPERATIONS

LAST 5 YEARS

63%
neutron source uptime

6,343
beam days delivered

563
beam time allocations

92%
total beam time allocated to users

MORE THAN
70,000
beam days delivered
LIFETIME

MORE THAN
6,000
beam time allocations
LIFETIME

MORE THAN
80%
total beam time allocated to users
SINCE 1997

TRAINING HIGHLY QUALIFIED PEOPLE

Drew Marquardt performed many experiments at the CNBC as a student. He is now a professor at the University of Windsor, where he continues conducting research using neutron beams.

As a student, Laura Toppozini (left) worked directly with CNBC scientist Zahra Yamani (right) on an experiment. Toppozini is now a financial analyst at Neuberger Berman Breton Hill ULC.

MATERIALS RESEARCH FOSTERS TRANSFERRABLE SKILLS THAT REACH WELL BEYOND THE LABORATORY

Science generates valuable knowledge in the young people who pursue scientific fields of study during their formal education. In addition to developing students' hard analytical skills, participation in the scientific process also develops soft skills like confidence and networking.

The Canadian Neutron Beam Centre has assisted many university users by providing a large number of students and post-doctoral researchers with hands-on experiences in conducting challenging experiments.

Some of these young people, stirred by the prospect of making important scientific discoveries, have stayed in science throughout their careers. Many others have gone on to apply their new skills to professions in business, industry, or government. Regardless, their scientific backgrounds enable these individuals to enhance Canadian innovation and competitiveness across the board.

LAST FIVE YEARS	SINCE 1984	SINCE 1984	SINCE 1992
151	**1000** EST	**75%**	**13**
students and post-docs trained on site	students and post-docs trained on site	of students conducting research at the CNBC earned a PhD	Canadian Neutron Scattering Summer Schools
		Source: Strapolec	

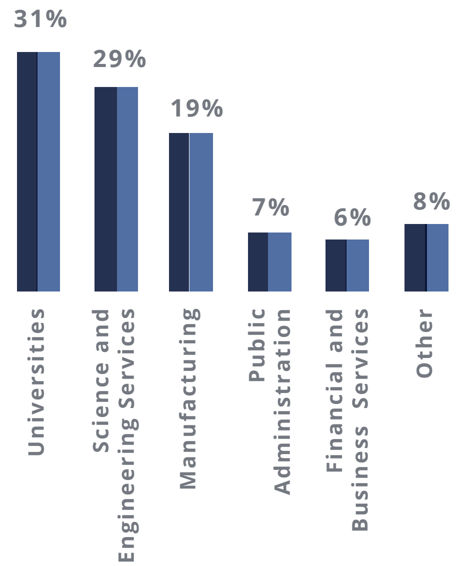
THE CNBC COMMISSIONED A STUDY ON A SAMPLE OF 300 OF THE VISITING STUDENTS AND POST-DOCTORAL RESEARCHERS. NEARLY HALF OF THESE STUDENTS WERE UNDERGRADUATES OR MASTER'S STUDENTS WHEN THEY VISITED THE CNBC FOR PART OF THEIR EDUCATION.

HERE'S WHAT IT DISCOVERED ABOUT THESE CNBC 'ALUMNI':

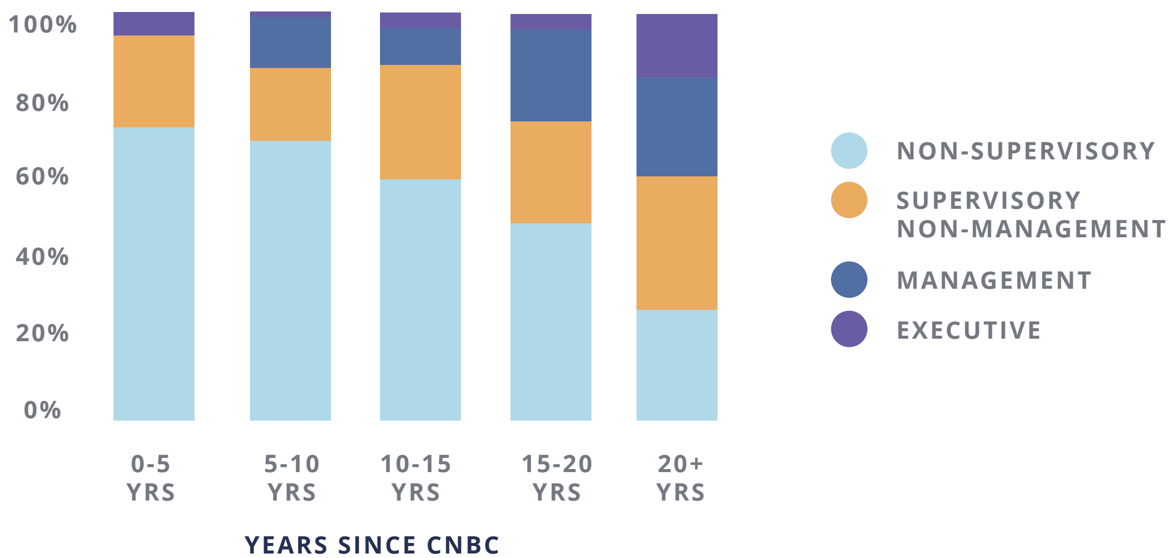
SOURCE: STRAPOLEC

EMPLOYMENT OF CNBC ALUMNI

- Over 75% of the students went on to earn a PhD—an astounding indication of the effect of the CNBC experience on students' aspirations.
- CNBC alumni have gravitated to where Canada needs their skills most. Today, many are working in core areas of R&D in the sectors that contribute most directly to Canadian innovation: manufacturing, higher education, and professional and technical services.
- A higher proportion of CNBC alumni are working in industry over academia, as compared to the average for natural sciences graduates in Canada.



CAREER PROGRESSION OF CNBC ALUMNI



COMMON THEMES AMONG CNBC ALUMNI INTERVIEWED ABOUT THE CNBC'S IMPACT ON THEIR CAREERS:

- Through pressure to complete an experiment in limited time, they learned disciplined research skills, including attention to detail and planning
- Through exposure to industry-oriented researchers, they gained an appreciation for applied sciences and were attracted to industry careers
- Through exposure to a safety and security culture, they were more prepared for the cultures of the industries they entered
- They valued learning directly from highly skilled researchers, who were respectful and helpful throughout their entire visit
- They valued the opportunity to use state-of-the-art materials research tools and techniques that were only available at the CNBC
- They valued learning to perform in a sophisticated national laboratory environment, which prepared them for working in complex industrial environments

DR. THOMAS MASON
DIRECTOR OF A US NATIONAL LABORATORY
Scientific R&D

AT CNBC: 1987–1990

Investments in the CNBC encouraged Dr. Thom Mason to attend McMaster University, which provided access to the CNBC. The knowledge he subsequently gained at the CNBC regarding materials research using neutron beams was crucial to his career. Mason used the CNBC again as a university faculty researcher. Later, new investments at Oak Ridge National Lab attracted him to the US. "The CNBC had a big influence on my life, and I wouldn't have become the scientist I am today without it."

DR. RIAZ SABET-SHARGHI
VICE PRESIDENT OF TECHNOLOGY
Oil and Gas

AT CNBC: 1995–1999

Without access to the CNBC, Dr. Riaz Sabet-Sharghi's PhD "would not have been possible." His time at the CNBC remains relevant to his current research in non-destructive testing technologies for pipelines. Sabet-Sharghi says the CNBC taught him the importance of attention to detail in research and the need to take safety seriously. "From a research perspective, the CNBC was a gold mine whose research capabilities are irreplaceable."

PROF. CHRIS WIEBE
PROFESSOR AND TIER II CANADA RESEARCH CHAIR

Academia

AT CNBC: 1997-2002

Use of the CNBC's neutron facilities was important to Prof. Chris Wiebe's over 120 publications. CNBC experience taught him how to think critically, interpret data, and select research topics. The CNBC's closure puts Wiebe's research program at risk and results in a loss of assets for Canada's next generation of researchers. "Every major industrialized country has a neutron source other than Canada, and Canadian scientists will be begging for access to overburdened international facilities."

REBECCA TODA WORDEN
SENIOR MANAGER

Finance

AT CNBC: 2008

Experience with neutron beam diffraction was an important asset that helped Rebecca Toda Worden gain a job in nuclear engineering after graduating from her Master's program. The skills and research method she developed at the CNBC have been useful in her later career in the financial sector. "My time there is a marked chapter in my life that continues to make me proud."

DR. JENNIFER JACKMAN
DIRECTOR OF A NATIONAL LABORATORY

Scientific R&D

AT CNBC: 1980–1983

The CNBC and its staff facilitated Dr. Jennifer Jackman's pursuit of a doctorate at a time when only 3% of PhD graduates were female. The CNBC permanently changed its policy to allow Jackman and other pregnant women to safely conduct research. Without the knowledge and credentials she gained at the CNBC, Jackman would not have been able to become the Director of one of Canada's national laboratories. "It is not a stretch to say the CNBC formed my path to becoming a senior scientist."

DR. SUSAN BURKE
DIRECTOR OF MATERIALS SCIENCE

Pharmaceuticals/Healthcare

AT CNBC: 2004

According to Dr. Susan Burke, the CNBC's neutron scattering capabilities were vital to Canadian product development by providing an irreplaceable perspective for materials research. Additionally, the CNBC's serious approach toward safety was highly influential to Burke's outlook in the private sector. "It is a sad state for Canada if there aren't scientists working at the CNBC. Materials science research is important. Materials are in everything."

THE CNBC FORMED MY PATH TO BECOMING A SENIOR SCIENTIST.

- DR. JENNIFER JACKMAN

DR. MATTHEW HARDING
PROGRAM MANAGER
Aerospace

AT CNBC: 2011–2012

The CNBC taught Dr. Matthew Harding the value of neutron scattering to materials research. The significant role that the CNBC played in Canada's scientific research history was inspiring to Harding, and it led him to incorporate neutron scattering into his university teaching curriculum. Harding's research at the CNBC also contributed to his PhD, which ultimately led to his job in the aerospace industry. "I wouldn't trade my time at the CNBC for anything."

DR. DANIEL CLUFF
FUEL R&D SCIENTIST
Scientific R&D

AT CNBC: 2011–2013

Neutron beams at the CNBC provided Dr. Daniel Cluff with research capabilities that x-rays at his university could not provide. The knowledge and skills he developed while at the CNBC have proved useful in his subsequent career in the private sector. "It is a shame there will no longer be a neutron facility in Canada as Canadian scientists will lose an essential source for valuable research."

DR. PABLO PRADO
CO-FOUNDER AND PRESIDENT
Professional Services

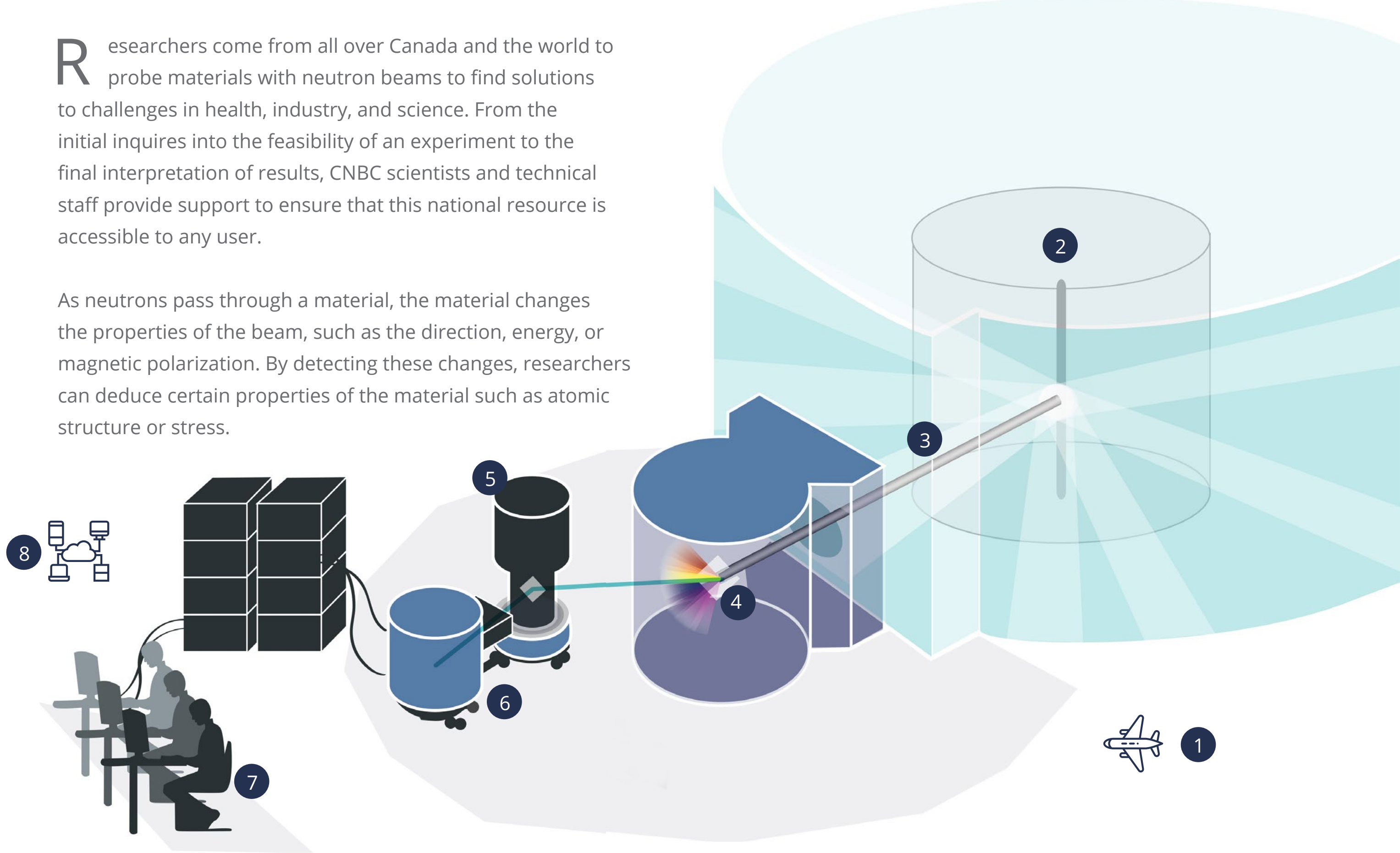
AT CNBC: 1992–1997

Neutron diffraction experiments at the CNBC were a key component of Dr. Pablo Prado's PhD. Additionally, observing how this sophisticated national laboratory co-ordinated and organized experiments in an efficient manner was beneficial to his career outlook. "The CNBC taught me about neutron diffraction; the whole experience was positive."

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 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.



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

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.

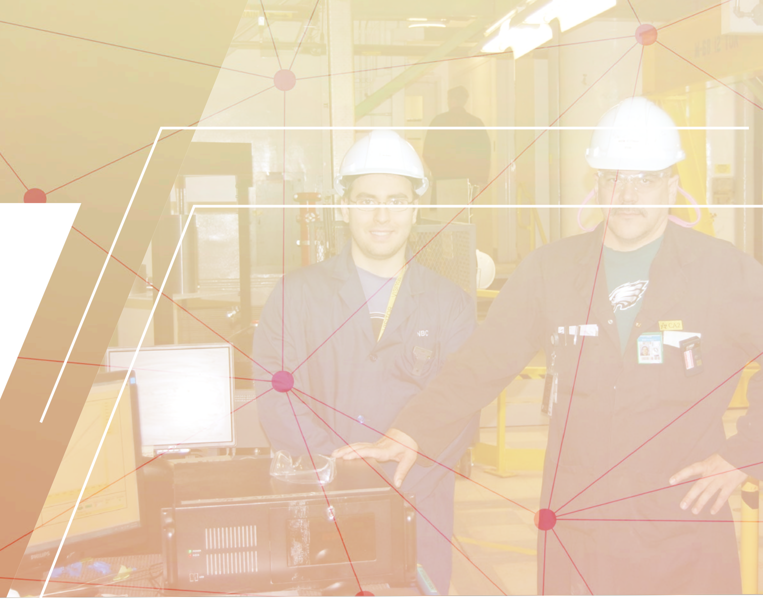
4. BEAM PREPARATION A crystalline material diffracts the beam, that is, it divides the beam according to the energies of the neutrons. A channel is positioned to allow only neutrons of a certain desired energy to proceed to the sample material. The remaining neutrons are absorbed in the wall of the large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

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.

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

7. USER INTERFACE AND ELECTRONICS A specialized electronic system controls each portion of the beamline and collects the experimental data. Workstations provide the user interface to control the experiment and perform preliminary data analysis.

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.



STORIES OF RESEARCH IMPACT

INCREASING THE BIO-COMPATIBILITY OF MEDICAL DEVICES

Neutron beams reveal the molecular mechanisms behind a new technology that could reduce the risk of complications and death from heart bypass surgery and dialysis. Michael Thompson of the University of Toronto has designed a surface coating that ensures medical devices are compatible with the body fluids they contact. Without such protection, devices can trigger blood clots during surgeries and can interfere with diagnostic tests when body fluid proteins stick to the surface of medical devices—a process called 'fouling.' Now, Thompson is working with a spin-off company, Econous Systems Inc., to further develop and commercialize his discoveries. Thompson and Econous accessed the CNBC to test their ideas about how their coatings work. The results showed that the coating induces a 'nano-gel' in the water layer above its surface, and this nano-gel enhances the coating's protective effect. "Our research has provided a general rationalization of the anti-fouling mechanism, giving us confidence that our technology is uniquely suited for the applications we are pursuing," says Thompson. Econous is now applying one of Thompson's coatings to develop a low-cost blood test for the early detection of ovarian cancer.

SOURCE: HTTP://CINS.CA/2016/10/26/BIO-4

NEUTRON BEAMS HELP SHED LIGHT ON ALZHEIMER'S DISEASE

University of Waterloo scientists are putting together pieces of the molecular puzzle behind Alzheimer's disease by examining the role of disease-related biomolecules in model brain cell membranes. About 50 million seniors worldwide live with Alzheimer's disease or similar dementias. These diseases disrupt the normal functions of brain cells, leading to memory loss and cognitive impairment. A number of changes are known to occur in cellular membranes with age, and University of Waterloo professor Zoya Leonenko has been exploring which of these changes could trigger buildups of a certain protein, called amyloid, that damages brain cell membranes. Leonenko's research team used neutron beams at the CNBC to test hypotheses about the role of membrane structure, and also to gain insights about how cholesterol and melatonin biomolecules might affect that structure on the molecular level. The neutron beam results showed clearly that cholesterol and melatonin had opposite effects on membrane structure, with melatonin possibly playing a protective role against amyloid damage. "Our research findings are all steps along the way that we hope will lead to development of a way to prevent or treat Alzheimer's disease," says Leonenko.

SOURCE: HTTP://CINS.CA/2018/12/04/ALZHEIMERS

CLARIFYING THE ROLE OF VITAMIN E

Using neutron beams at the CNBC, scientists from Brock University gathered direct molecular-level evidence of Vitamin E's role in the body—a feat that has been unattainable using other experimental techniques, largely because this vitamin is difficult to observe in action. Conventional wisdom has suggested that Vitamin E might play a 'preservative' role in the human body by protecting the oily parts of cell membranes, but scientific doubts have persisted. Thad Harroun's research team at Brock University accessed the neutron beamlines at the CNBC to see how Vitamin E interacts with a cell's lipid bilayer on the molecular level. The results revealed "a very efficiently designed system," observes Harroun, "which is why it can be effective even though our bodies retain in our membranes only a small portion of the Vitamin E we consume." In follow-up studies, they found that Vitamin E could behave quite differently depending on the kind of bilayer used during laboratory testing. "This discovery explains years of conflicting and inexplicable observations of Vitamin E's behaviour in [these] bilayers," says Harroun. They also found more evidence of its preservative role: "We're saying the conventional wisdom is correct. Vitamin E is an antioxidant."

SOURCE: HTTP://CINS.CA/2016/09/27/BIO-3

SCIENCE TO SOLVE WORLD HUNGER: NEUTRON RESEARCH WITH PLANTS

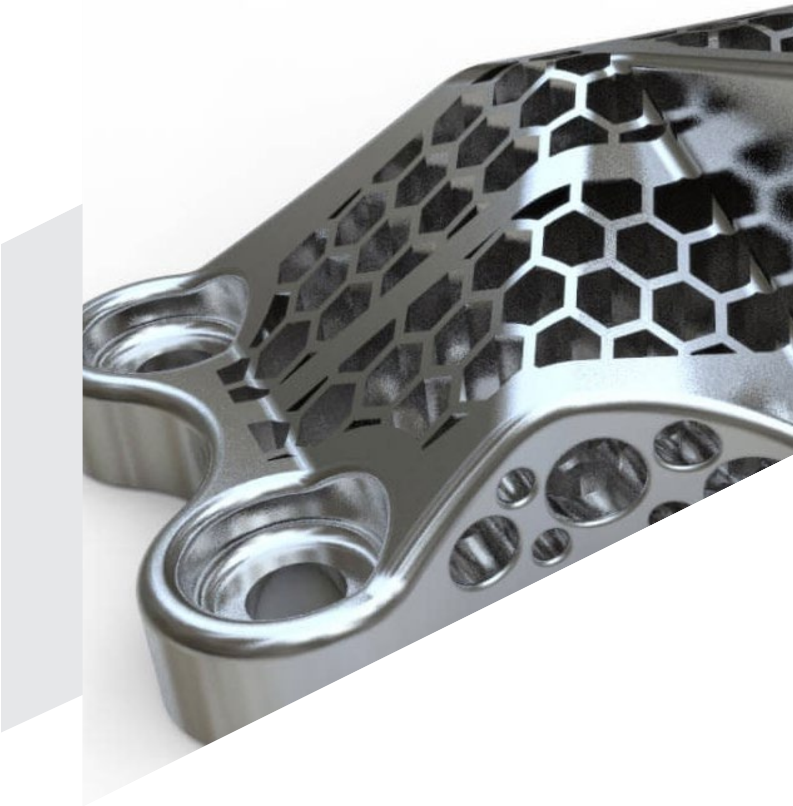
University of Saskatchewan scientists are using neutron beams to observe plant roots in soil to aid in the breeding of drought-resistant crops. With the global population expected to reach 9 billion by 2050, there is a pressing need worldwide to develop crops that can withstand dry environments, that are better able to acquire nutrients, and that are more nutritionally sound. What happens below ground is critical to a plant's ability to make efficient use of water and nutrients, but the scientific community has relatively limited understanding of how these processes work. Fortunately, neutron imaging is beginning to give scientists a look into that sub-surface world. Neutrons can penetrate the soil and provide insights into the workings of a plant's root system on the molecular level. A University of Saskatchewan research team, led by Emil Hallin, has been using neutron beams in conjunction with x-ray imaging to get a more complete profile of a plant's otherwise hidden systems. Ultimately, the team hopes these insights will assist in the development of crops that can feed the world's rising population even as farming conditions become increasingly demanding.

SOURCE: HTTP://CINS.CA/2017/05/04/AGRICULTURE

UNDERSTANDING CHOLESTEROL AS AN ESSENTIAL NUTRIENT

An international research team led by Thad Harroun at Brock University has used neutron beams to resolve a scientific controversy over cholesterol. Cholesterol is a necessary component of every cell membrane. It is instrumental in forming structures within the membranes that have many purposes, including helping the cell to interact with its surroundings and producing Vitamin D and hormones. But the extent of cholesterol's functions within cell membranes, and exactly how it interacts with lipids and proteins to accomplish those functions, are still open scientific questions. To help find answers, Harroun and his team used neutron beams at the CNBC to study cholesterol in model membranes—and ended up making controversial discoveries about the location and orientation of cholesterol in the membrane. The controversy led the team to form an international research collaboration that returned to the CNBC for further studies, which eventually put the controversy to rest. In the process, scientists have gained more certainty about cholesterol's location and orientation in the cell membrane, enabling them to proceed further with unravelling how cholesterol molecules interact with proteins to form critical membrane structures.

SOURCE: HTTP://CINS.CA/2017/03/03/BIO-5



NEUTRON BEAMS HELP TO ADVANCE THE 3D PRINTING INDUSTRY

SOURCE: HTTP://CINS.CA/2018/07/06/3D-PRINTING

After using neutron beams to gather data on why 3D printing sometimes fails, one industry–university collaboration can now offer more reliable printing algorithms. Additive manufacturing, more commonly known as 3D printing, is a way to make small batches of unique or specialized metal parts (e.g., airplane and car parts) without the high cost of tooling up a factory. Additive manufacturing generates over $6 billion per year, and the industry is growing rapidly. But stress in the metal during printing can lead to distortions in the final product. A research team led by the University of Pittsburgh used neutron beams at the CNBC to help resolve this problem. The team collaborated with ITAMCO, a 3D printing software company that helped the researchers determine what tests would produce the most useful results. The CNBC data enabled the researchers to relate the part's internal stresses to the support structures used during the printing process, and also to the orientation of the part as it was being printed. The results "provided valuable experimental checks to boost the accuracy of our software's ability to find the best orientation to produce the part," says Joel Neidig, Chief Technology Officer at ITAMCO.

ENSURING OIL AND GAS PIPELINE INTEGRITY USING NEUTRON BEAMS

A university–industry collaboration used neutron beams at the CNBC to inform updates to industry guidelines for the safe operation of oil and gas pipelines in Canada. Since over 97% of the oil and gas produced in Canada is transported through pipelines, it is critical for the pipeline industry to understand exactly how pipeline materials behave as they age. Indeed, the Canadian energy sector has standard practices to ensure that oil and gas pipelines remain safe. For the past decade, these practices have been influenced by a team of researchers led by Weixing Chen at the University of Alberta, who used neutron beams at the CNBC to better understand stress and corrosion in pipeline steel. Chen collaborated with TransCanada Pipelines and NOVA Research & Technology to reproduce and study a form of cracking observed in older pipelines. “Neutron diffraction was the only method we could have used to measure the stress,” says Chen. His team’s observations had an immediate impact, leading the industry to update its guidelines for identifying and dealing with these cracks. Chen has continued to use these results to develop better computer models to predict pipeline lifetimes—models that are now being used by TransCanada Pipelines, Enbridge, and member companies of the Pipeline Research Council International.

SOURCE: HTTP://CINS.CA/2017/09/27/PIPELINE

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.

NEUTRON EXPERIMENTS ADD CONFIDENCE TO NUCLEAR REACTOR SAFETY

Canadian Nuclear Laboratories, a leader in sciences that are foundational to reactor safety, used neutron beams to add further confidence in lifetime predictions of critical components in nuclear power stations. CANDU reactors don't require enriched fuel to operate because they use heavy water, which allows for the use of natural, unenriched uranium as fuel. For most other purposes, heavy water behaves similarly to light water, enabling Canada to rely on some of the scientific knowledge generated in the light water reactor industry. For example, the lifetime prediction of critical components like heat exchanger tubes in CANDU reactors is often based on corrosion rates determined in light water. To verify whether these lifetime predictions are just as accurate in heavy water conditions, Hung (Harry) Ha at Canadian Nuclear Laboratories used neutron beams at the CNBC to study the corrosion of nickel and nickel alloys, which are used in reactors' heat exchanger tubes. Results so far have confirmed that the corrosion rates in heavy water are similar to those in light water, adding confidence in the accuracy of the lifetime predictions.

SOURCE: HTTP://CINS.CA/2017/11/10/NUCLEAR-5

LOWERING THE COST OF ENERGY-SAVING TECHNOLOGY FOR CARS AND AIRPLANES

Dalhousie University engineers are using neutron beams to develop inexpensive ways to process lightweight shape memory alloys for actuators that save energy in cars or airplanes. A shape memory alloy remembers its original shape after it is deformed—and can return to that shape when activated. One of many energy-saving applications of these materials is to harness this remarkable ability to create a push or pull needed to fold airplane wings during flight, and thereby replace heavier, more energy-intensive electric motors and hydraulics. Steve Corbin at Dalhousie University is sponsored by aerospace and automotive companies to develop low-cost ways of processing nickel-titanium shape memory alloys into parts. One method he is looking into is the sintering of metal powders. Corbin's team came to the CNBC to determine what metal phases were forming—and at what temperatures they were forming—during the sintering process. "We've cleared up much of the confusion about what's going on in these materials during sintering," says Corbin. "This is an important contribution to the field because it provides the fundamental knowledge required to optimize the sintering process for inexpensive nickel-titanium shape memory alloys, which are needed for lightweight actuators in cars and airplanes."

SOURCE: HTTP://CINS.CA/2018/03/07/ENERGY-SAVING-TECH-CARS-AIRPLANES

DESIGNING NEW PERMANENT MAGNETS FOR WIND TURBINES AND ELECTRIC VEHICLES

McGill University physicists are using neutron beams to develop a method to accelerate the search for new low-cost magnets for more energy-efficient wind turbines and electric vehicles. Permanent magnets are starting to be used in wind turbines and electric vehicles to boost energy efficiency. However, strong magnets are expensive and mining the rare-earth minerals for these magnets produces a disproportionate amount of greenhouse gases. Finding a cheaper and greener magnetic material is not easy, as there are thousands of possible magnetic compounds that have never been made. Zaven Altounian and Dominic Ryan at McGill University are trying to accelerate the search by developing a reliable way to predict the magnetic properties of a material even before it is made. They accessed neutron beams at the CNBC to examine new materials they had made, with the aim of verifying their model's predictions of the magnetic properties of these materials. The results indeed verified some key aspects of their model and also suggested a path forward for designing a better magnetic material.

SOURCE: HTTP://CINS.CA/2017/01/20/WIND

NEUTRONS AID INVESTIGATIONS INTO CLEAN HYDROGEN TECHNOLOGY

Tomorrow's trucks, trains, and ships could be powered with clean hydrogen technology that exists today—and discoveries made by Canadian physicists could help make this sustainable technology safer and more efficient. When hydrogen is burned as fuel, its only by-product is water. Fuelling vehicles is just one of the reasons behind the 2017 formation of the Hydrogen Council, a 24-member industry consortium with $10 billion to invest in developing and deploying hydrogen technology. In light of such increased interest in hydrogen-powered vehicles, Jacques Huot at Université du Québec à Trois-Rivières is seeking to eliminate any risk of a hydrogen gas fire in a transportation accident. His research aims to identify a material for storing hydrogen that meets performance standards set out by the US Department of Energy. His quest for such a material has led him to investigate metal hydrides. Together with Julien Lang from Canadian Nuclear Laboratories, Huot accessed the CNBC to study the behaviour of hydrogen within Mg_2FeH_6, an iron metal hydride. Using neutron beams, the researchers gained key insights about the material, including that the iron catalyses the separation of the hydrogen gas molecules. Huot and Lang have since continued their collaboration to further unravel the complexities of these metal hydrides.

SOURCE: HTTP://CINS.CA/2017/12/13/HYDROGEN

SUPERCAPACITORS FOR CLEAN ENERGY TECHNOLOGIES

Neutron beams have provided insights into the nanoscale workings of supercapacitors, an enabling technology for innovations that improve wind turbines, solar cells, light rail trains, and electric vehicles. Wind turbines and solar panels use supercapacitors to stabilize their electricity output when wind gusts or moving clouds cause fluctuations in energy production. Some light rail trains use supercapacitors to recharge quickly during stops, avoiding the need for overhead wires. And electric cars use supercapacitors to save energy through regenerative braking. However, today's supercapacitors are limited by their low energy storage capacity. David Mitlin at Clarkson University is studying materials, such as cobalt oxide, that have higher energy storage capabilities. But what gives rise to cobalt oxide's superior storage ability was not understood until Mitlin made very thin films of it and brought them to the CNBC for study. The findings explained discrepancies between the predicted and actual energy storage performance of this material. This experiment provided invaluable insights for Mitlin's parallel research on supercapacitors in general. In fact, he has patented several of his ideas for improved supercapacitors and is now pursuing commercialization.

SOURCE: HTTP://CINS.CA/2016/11/15/ENERGY-3

BASIC RESEARCH SHEDS LIGHT ON NEW MATERIALS FOR ENERGY APPLICATIONS

Scientists regularly access neutron beams to gain fundamental insights into the inner workings of new materials, including some with potential for clean energy applications. Often, basic research on new materials is needed to lay the scientific foundations for future technological developments. For example, the scientific community regularly produces new materials and then analyzes them with an array of tools to gain a fundamental understanding of their properties. Mario Bieringer at the University of Manitoba and John Greedan at McMaster University are examining new materials in the perovskite class. Perovskites are often used in clean energy applications, such as fuel cells, energy storage, and the conversion of waste heat into useful energy. Using neutrons at the CNBC, Bieringer and Greedan have generally been able to solve these new materials' atomic and magnetic structures, thereby providing a solid foundation of knowledge on which to base future research and development for clean energy technologies involving perovskites.

SOURCE: HTTP://CINS.CA/2016/12/16/BASIC-ENERGY-RESEARCH

DEVELOPING THE ULTIMATE LIGHTWEIGHT ALLOY FOR CLEANER CARS

Engineers from the University of Waterloo applied neutron beams in the development of a promising new cost-effective magnesium alloy that has better ductility and strength—paving the way for lighter, more energy-efficient vehicles. The prospect of producing vehicles that weigh less and use alternative fuels is a leading motivation behind Ford Motor Company's recent $1.2 billion investment in its Canadian research and manufacturing facilities. And Ford is not alone; all major car makers in North America and Europe are pursuing lightweight materials to help them meet environmental targets. Magnesium is the lightest of all engineering metals, but its alloys "haven't been widely adopted by car makers for reasons such as cost, manufacturing limitations, and performance," notes Shahrzad Esmaeili of the University of Waterloo. Compared to steel, "available magnesium alloys are less ductile, and their strength is typically lower," Esmaeili explains. "But we have made progress by creating magnesium alloys that alleviate these problems." Her research team used neutron beams at the CNBC to characterize the texture in a new magnesium alloy the team had created. The results provided explanations for the alloy's improved ductility, and also offered insights into how the alloy might be optimized further.

SOURCE: HTTP://CINS.CA/2017/05/03/AUTO-5

HELPING CARS LOSE WEIGHT AND GO GREEN

In partnership with industry, Dalhousie University researchers are using neutron beams in studies aimed at opening up the automotive market to more products made from aluminum powders—a promising alternative to the heavier steel components used in the industry today. A car's weight affects its environmental footprint for two main reasons. First, lighter cars use less fossil fuel. Second, it's just more feasible for lighter vehicles to use other fuels. With this in mind, Paul Bishop of Dalhousie University is collaborating with GKN Powder Metallurgy to develop aluminum powder metallurgy technology that could be vital for making lightweight car parts. Since strength is also a priority in vehicle manufacturing, Bishop accessed the CNBC to gain a molecular-level understanding of the strength of parts created using aluminum powders. The findings are exciting because they offer significant promise for increasing strength. "The collaboration of GKN and Dalhousie has significantly pushed the technology to mainstream uses," says Alan Taylor, Vice President of Lightweight Technology at GKN. "The current study has the potential to enhance mechanical properties further and to extend the applications of these materials."

SOURCE: HTTP://CINS.CA/2016/12/01/AUTO-4

BOOSTING THE FUEL EFFICIENCY OF JET ENGINES

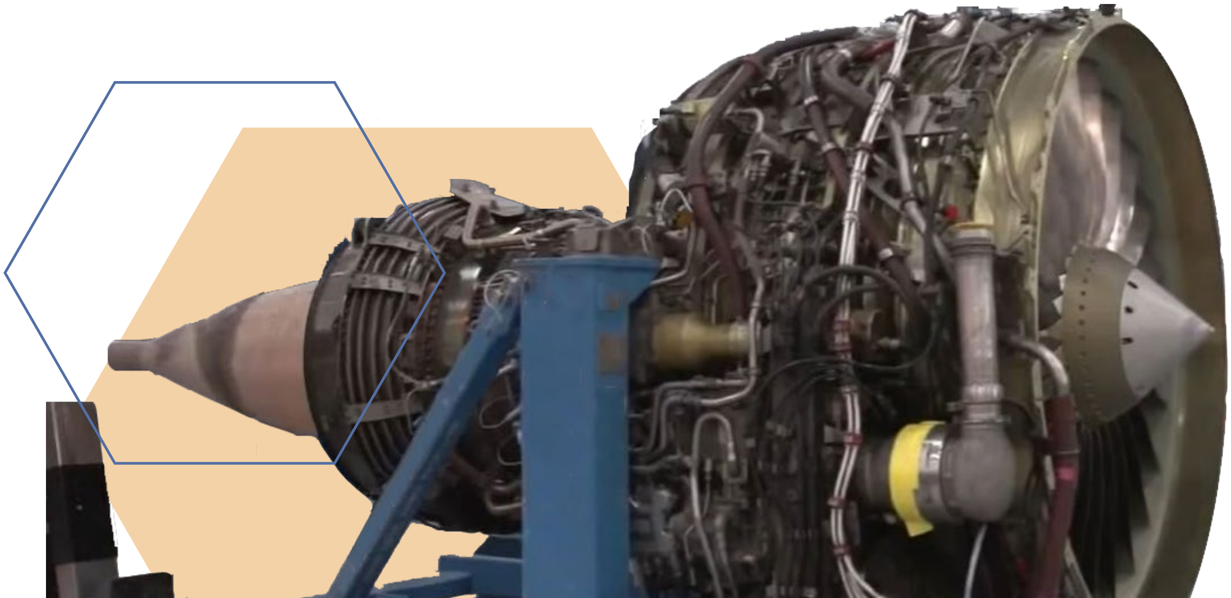
After collaborating with University of Cambridge scientists to study new alloys using neutron beams, Rolls-Royce has applied to patent a new material for use in higher-efficiency jet engines. Jets produce much more greenhouse gases than a car or truck, but the aerospace industry is working hard to reduce its environmental footprint. Making jet engines one percent more efficient would be "like taking 100 to 200 cars off the roads for each plane with a better engine," says Katerina Christofidou, a post-doctoral researcher at the University of Cambridge. One way to make a jet engine more efficient is to increase its operating temperature, but better materials are needed to withstand the heat. In collaboration with Rolls-Royce, Christofidou set out to explore how incremental changes in the chemical compositions of nickel-based alloys could raise an engines' safe operating temperature. She accessed the CNBC to examine her variant alloys to determine what made some of them stronger than others. The Cambridge team has since input her results into predictive computer models to identify other incremental changes that might lead to further improvements. Notably, this data has informed Rolls-Royce's recent decision to make, study, and apply to patent a new material.

SOURCE: HTTP://CINS.CA/2017/01/10/AERO-3

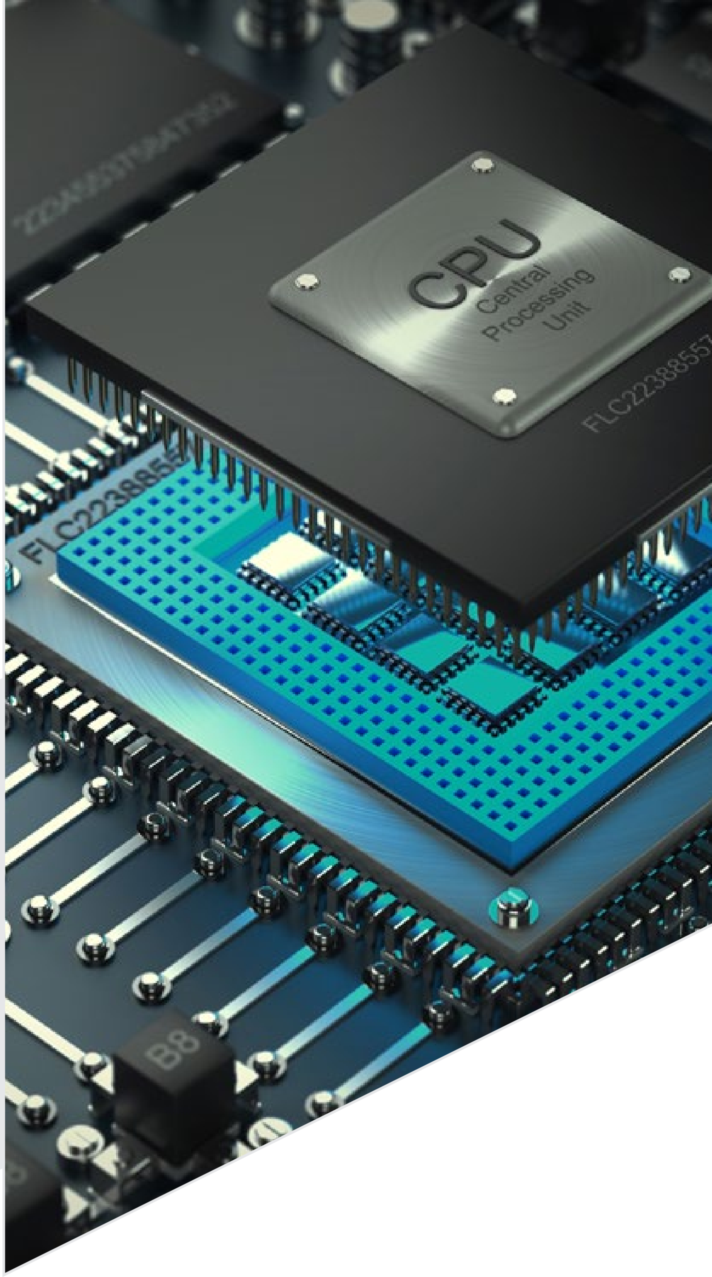
DEVELOPING TECHNOLOGY FOR REPAIRING ADVANCED JET ENGINES

Government and academic researchers used neutron beams to test a new repair technology capable of supporting the aerospace industry in adopting more fuel-efficient jet engines. A team of Canadian researchers is developing a low-cost way to repair more fuel-efficient engines jet engines, because such a repair method is needed before commercial airlines can feasibly adopt them. The team, headed by the National Research Council, includes experts from the University of British Columbia at Okanagan and the CNBC. StandardAero, a jet engine repair company, has provided the team with technical information about standard practices so that the results will be useful to the whole industry. The research included replicating the key aspects of an advanced engine repair in which a damaged blade is cut out and a new blade is welded into place using the proposed repair method, called linear friction welding. To ensure the repaired blade will function reliably while in service, neutron beams at the CNBC were used to non-destructively measure the stress inside the welded blade. So far, the findings suggest that the proposed repair method is a promising technology for refurbishing jet engines.

SOURCE: HTTP://CINS.CA/2017/02/01/AERO-4



DEVELOPING NEW MAGNETO-ELECTRIC TECHNOLOGY FOR FASTER COMPUTERS



American researchers who accessed the CNBC to gain insights into a new material are now collaborating with Intel to explore a potential breakthrough in computer processing and memory. Advancements in computing have slowed in recent years due in large part to the heat generated every time information is read or written to computer processors and memory chips. “It’s much more energy efficient to use voltage for this purpose instead of current, and therefore less heat is produced,” explains Ichiro Takeuchi at the University of Maryland. Takeuchi and his collaborators have demonstrated a prototype device based on this principle. It uses thin films of a multiferroic material (i.e., a material whose magnetic state can be controlled using voltage). Recent advances in polarized neutron diffraction driven by Zahra Yamani of the CNBC have made this technique sensitive enough to detect magnetic field changes in thin films of materials similar to those used in Takeuchi’s prototype device. William Ratcliff from the NIST Center for Neutron Research led a series of neutron experiments at the CNBC to better understand the films’ underlying mechanisms—knowledge that gave confidence to the notion that Takeuchi’s device could be scalable down to mere tens of nanometres in size, which is how small it would have to be to compare with current electronics. Takeuchi is now collaborating with Intel to find ways to shrink his potentially ground-breaking device.

EXPLORING MATERIALS FOR 'RACETRACK' MEMORY

Dalhousie University scientists accessed the CNBC to identify materials with the magnetic properties required for a major breakthrough in computer memory.
When a computer shuts down, all the data in its fast short-term memory is lost. When it is turned back on, it takes time to reload its short-term memory out of its slower, long-lasting memory. Scientists at IBM have devised a profoundly different concept for computer memory that combines the advantages of both speed and permanence. Realizing this concept, dubbed 'racetrack memory,' would allow computers and devices to access enormous amounts of data in a billionth of a second, radically changing how computers work. Scientists, including Ted Monchesky at Dalhousie University, are on the hunt to identify materials that have the right properties to turn racetrack memory into a reality. Monchesky's research team accessed the CNBC to examine thin films of materials with exotic and intriguing properties, resulting in a series of exciting discoveries. Under the right conditions, these materials form 'skyrmions,' which can be thought of as the smallest possible magnetic domain. These skyrmions have three of the properties necessary for racetrack memory: they have high mobility, they are extremely small, and they last a long time.

SOURCE: HTTP://CINS.CA/2016/10/10/COMPUTERS-2

EXPLORING MATERIALS FOR FASTER COMPUTERS

Australian scientists accessed the CNBC in search of the right materials for the next generation of computer processors.
The heat generated in processor chips has limited chip speed since 2004, and the drive towards smaller transistors is reaching its limit as well. These factors suggest that silicon-based computer processors are now a mature technology that has reached a plateau. Therefore, in order to make further breakthroughs in processing power, new materials must be identified. "Spin electronics—or 'spintronics'—is a way to do more in the same tiny space because spintronic devices encode information using the electron spin as well as its charge," says Frank Klose of the Australian Nuclear Science and Technology Organisation. Scientists have been searching through thousands of materials for one with the right properties for spintronics. Klose's research team is focusing on rare-earth nitrides, which have strong magnetic properties useful for spintronics. His team accessed the CNBC to study them using neutron beams. During the experiments, samples of the rare-earth nitrides were held under extreme temperatures and magnetic fields, as was necessary to determine the fundamental properties of these materials. Some of the results were quite unexpected, stimulating further research and discussion within the scientific community.

SOURCE: HTTP://CINS.CA/2016/09/26/COMPUTERS

TIMELINE HIGHLIGHTS

1947 | PG. 30

The National Research Council completed the National Research Experimental (NRX) reactor

1949 | PG. 30

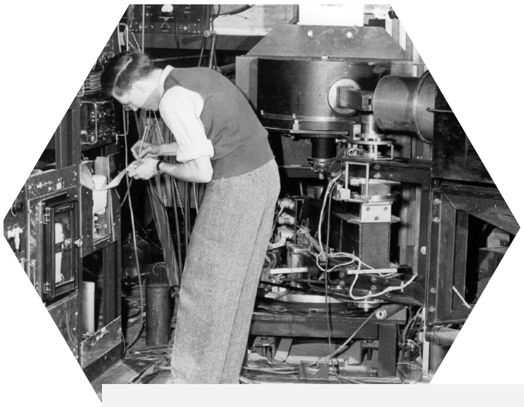
The first paper using neutron scattering was published by Norman Alcock and Don Hurst; it reported diffraction from oxygen and carbon dioxide gases

1952 | PG. 30

TIMELINE HIGHLIGHTS

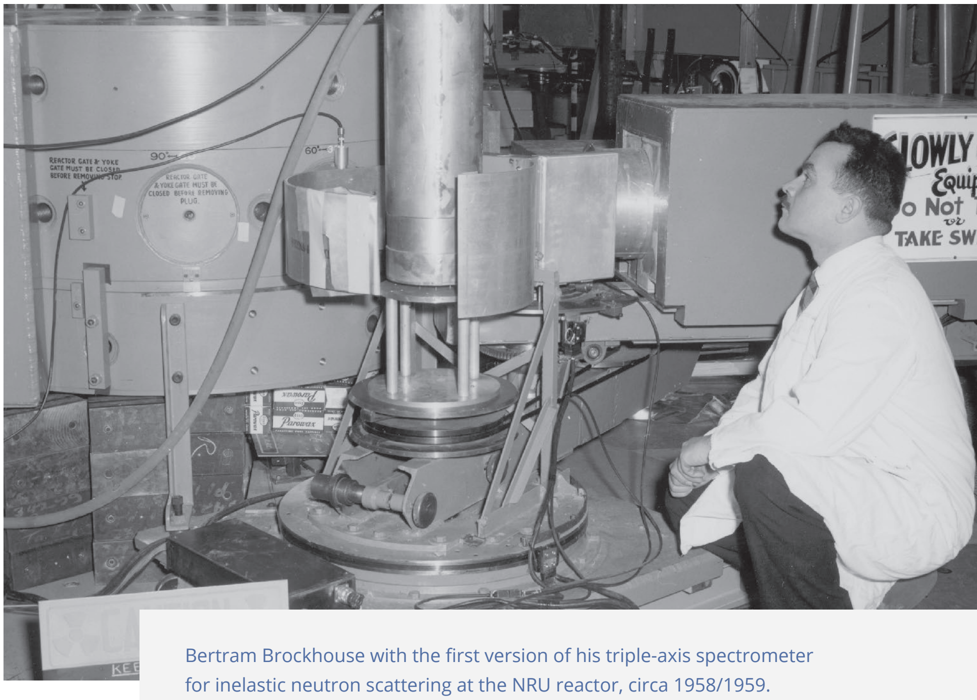
THE BEGINNING – 1940'S

Research using neutron beams grew out of the pioneering efforts of scientists at the National Research Council's Chalk River site. After the NRX reactor was completed in 1947, neutrons from the reactor were used for research. Don Hurst was the inspiration behind the neutron scattering program, gathering key scientists such as Trudi Goldschmidt, Andy Pressesky, Philip Tunnicliffe, Norman Alcock, and John Spiers. This ground-breaking team developed early neutron beamlines and demonstrated the enormous potential of neutron diffraction by solving the molecular structure of gases, such as carbon dioxide and oxygen, and of liquid deuterated ammonium chloride.



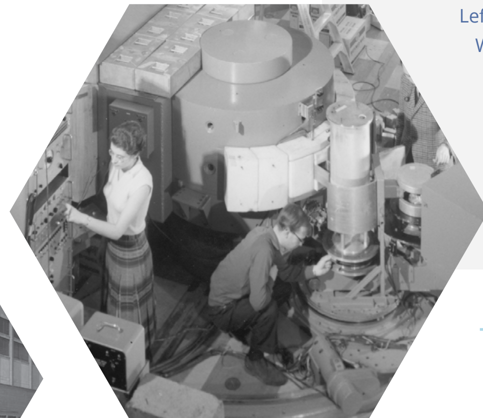
A neutron diffraction apparatus built in the 1940s at the NRX reactor under the leadership of Don Hurst. Here, Norman Alcock is shown reading a chart.

THE BROCKHOUSE DAYS – 1950'S



Bertram Brockhouse with the first version of his triple-axis spectrometer for inelastic neutron scattering at the NRU reactor, circa 1958/1959.

Don Hurst hired Bertram Brockhouse in 1950. The idea that the NRX reactor could demonstrate the use of inelastic neutron scattering to study solids first arose during a December 1950 discussion between Hurst, Brockhouse, Trudi Goldschmidt, and Noel Pope. Departures of several scientists by 1951 left only Hurst, Brockhouse, and Pope to carry forward the development of neutron scattering, until they were joined in the early 1950s by Dave Henshaw, Alec Stewart, and Warwick Knowles. Together, these scientists laid more foundation for neutron scattering experiments with gases, liquids, and solids. Brockhouse led both the examination of solids and the development of inelastic neutron scattering. The initial demonstration of inelastic neutron scattering using the first triple-axis spectrometer, which Brockhouse invented, was reported in 1955 by Brockhouse and Stewart. Then, in the same year, Brockhouse took over from Hurst as the leader of the scientific team. In 1958, Brockhouse developed the 'constant-Q' method, which greatly simplified inelastic neutron scattering experiments. These were pioneering accomplishments that led to Brockhouse's Nobel Prize in Physics in 1994, nearly 40 years later.



Scientists conducting neutron scattering on an early triple-axis spectrometer at the NRU reactor, circa 1964/1965. Left to right: Margaret Elcombe, Brian Powell, and Dave Woods. Elcombe was a young visiting scientist from Cambridge University in England and one of few women scientists in those days. She went on to a successful career in neutron scattering at the Australian Nuclear Science and Technology Organisation.

THE NRU REACTOR OPENS – 1957

The building that houses the NRU reactor at Chalk River Laboratories.

The NRU reactor began operating in 1957. Because this reactor was ten times more powerful, most of the neutron scattering research taking place at the NRX reactor moved there. In 1960, Neutron Physics became a separate branch of AECL and was headed by Bertram Brockhouse, reflecting the growing importance of neutron beams in physics research. Brockhouse left Chalk River in 1962 to become a professor at McMaster University, and he sent many of his graduate students back to the NRU reactor to do experiments.

In addition to enabling many neutron beam experiments over its lifetime, the NRU reactor was the primary facility for testing nuclear components in the conditions of a reactor core during the development of Canada's fleet of nuclear power stations. The NRU reactor also produced a large portion of the world's radioisotopes, such as molybdenum-99, and in this way it has aided in the medical diagnosis of an estimated 500 million patients around the world.

THE MIDDLE DECADES – 1960'S, 1970'S, 1980'S

The foundation laid by the site's early scientists made Chalk River Laboratories a world leader in using neutron beams to solve research questions about materials—and the next generation of scientists continued building on this legacy. Dave Woods became the leader of the neutron scattering team after Brockhouse left. Then, between 1961 and 1965, a new generation of neutron beam researchers joined AECL. Chief among them were experimentalists Gerald Dolling, Brian Powell, Bill Buyers, Peter Martel, Eric Svensson, and Tom Holden, along with theorist Varley Sears. The scientific contributions of this cohort characterized Chalk River's highly reputable neutron scattering program well into the 1990s, and users gained access by collaborating with these renowned scientists. In 1971, the Neutron Physics Branch became the Neutron and Solid State Physics Branch, reflecting the growing importance of neutron beams in materials research.

THE FIFTH STATE OF MATTER IN HELIUM – 1982

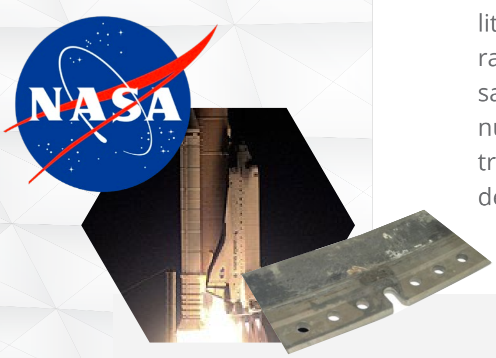
Over the course of their careers, Dave Woods and Eric Svensson performed an extensive series of measurements of the inelastic neutron scattering in helium at low temperatures. In the early 1980s, they worked with Varley Sears and Peter Martel to demonstrate the existence of a fifth state of matter in liquid helium. This fifth state, known as a Bose–Einstein condensate, causes helium to lose all friction and become a 'superfluid.' These four scientists achieved very precise measurements of the quantum mechanical properties of liquid helium. A number of their measurements stood as the world standard for many years, with some still remaining the most accurate to date.

Eric Svensson made major contributions to the science of superfluids.

APPLIED NEUTRON DIFFRACTION FOR INDUSTRY – **1983-2009**

In 1983, Tom Holden worked with Brian Powell and Gerald Dolling to demonstrate the stress scanning of intact nuclear power reactor components. The technique was then developed into a commercial service—one that was selected over its American counterparts to assist in the investigation into the 1986 Space Shuttle Challenger disaster. Neutron diffraction at the CNBC was used to study an as-manufactured section of a booster rocket casing that was identical to the one involved in the disaster. Results showed that the stress distribution in the casing's material was acceptable, redirecting the investigators to look elsewhere.

Subsequently, Chalk River became the go-to place for failure analyses for high-profile incidents, including the problematic Point Lepreau Nuclear Generating Station shutdowns in 1997 and 2001, the Space Shuttle Columbia accident in 2003, and the train derailment that spilled 800,000 litres of oil into Alberta's Lake Wabamun in 2005. This commercial service ran successfully for over 25 years, providing proprietary data to enhance safety, increase reliability, and optimize manufacturing processes in numerous sectors (e.g., the aerospace, automotive, rail, and marine transportation industries; metal production; the oil and gas industry; and defence manufacturing).



The investigators looking into the Space Shuttle Challenger disaster sent a section of a booster rocket casing to Chalk River for stress measurements.

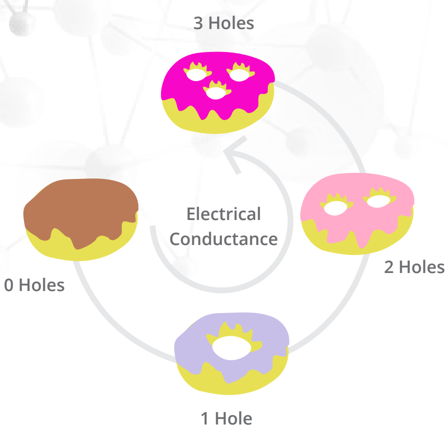
The Transportation Safety Board used the CNBC to understand rail fractures that led to the train derailment at Lake Wabamun, Alberta, and the resulting environmental disaster.

The neutron beam user community gathered to celebrate the opening of the DUALSPEC facility in 1992.

DISCOVERY OF TOPOLOGICAL MATERIALS – 1985

In 1985, Bill Buyers, together with Robin Armstrong of the University of Toronto, performed a key experiment on a crystal of $CsNiCl_3$. Results showed that the crystal could be classified as a totally new type of material distinguished by its topology. In other words, the discovery meant that the electrons in certain kinds of materials ('topological' materials) can organize collectively to produce properties that, like the number of holes in a donut, can only be identified by examining the object as a whole.

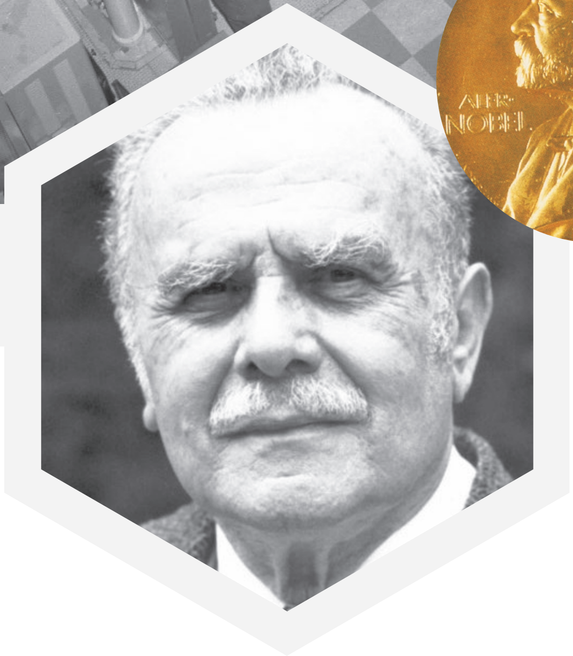
Topological materials had been predicted by mathematical theorists, including Duncan Haldane, who hypothesized that an energy gap (i.e., the Haldane gap) would appear in certain types of topological materials if they existed. However, these theorists were not taken seriously until Buyers' experiment overturned the wisdom of the day by confirming the existence of the Haldane gap. Over the next several years, Buyers and others followed up this discovery with more observations of similar behaviours in other materials, thereby proving the reality of topological materials. The theorists who had initially made the predictions were awarded the Nobel Prize in Physics in 2016, when the magnitude of this discovery's importance was better known.



Just as objects like donuts can be classified according to the number of holes, a material can be classified by the number of 'holes' in the collective organization of its electrons, referred to as its topological state. Some macroscopic properties, such as electrical conductance, can vary in a stepwise fashion depending on the material's topological state.

FORMALIZING THE USER FACILITY MODEL – 1992

The construction of two neutron beamlines, which comprised the DUALSPEC facility, marked a turning point for general user access to neutron beams at Chalk River. The $4 million construction and operations of DUALSPEC were funded jointly by AECL and grants from the Natural Sciences and Engineering Research Council (NSERC). The initial NSERC grant in 1985 was awarded to Malcolm Collins of McMaster University, which represented applicants from ten universities to ensure that DUALSPEC would be built and operated as a national user facility. In 1986, the Canadian Institute for Neutron Scattering was formed to represent users' collective interests in the facility. In 1992, when DUALSPEC opened, the Neutron and Solid State Physics Branch was renamed the Neutron and Condensed Matter Science Branch to better reflect the growing impact of neutron scattering in the fields of materials science, chemistry, and biology in addition to physics. Successful operation of DUALSPEC soon led to the adoption of a national user model for the other four neutron beamlines at Chalk River.



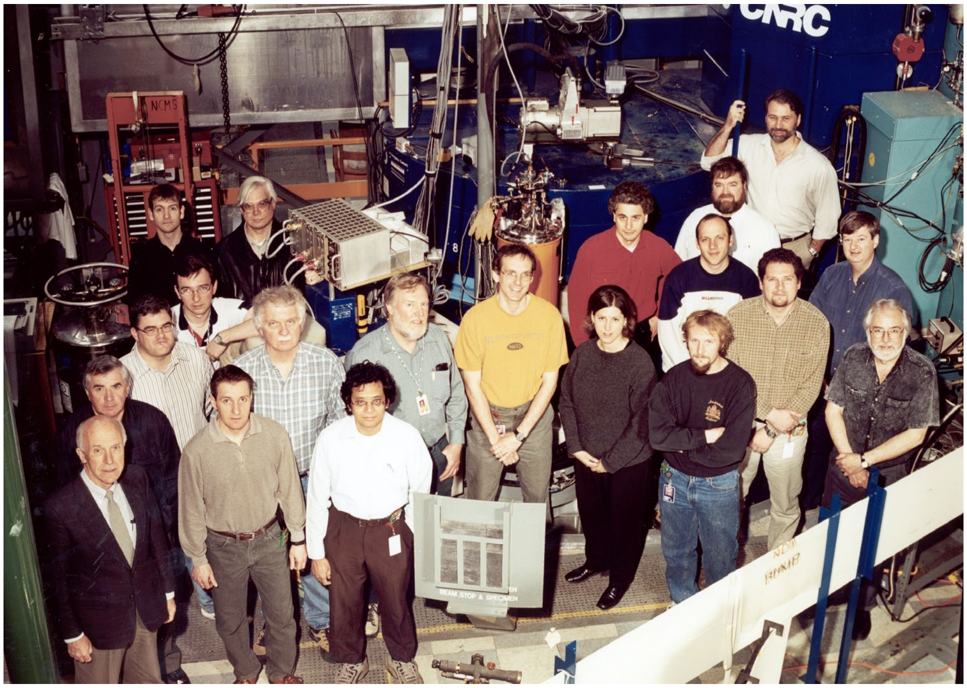
Bertram Brockhouse, circa 1994

Nobel Prize medallion.

THE NOBEL PRIZE IN PHYSICS – **1994**

Bertram Brockhouse shared the 1994 Nobel Prize in Physics with Clifford Shull of Oak Ridge National Laboratory in the US in recognition of their respective ground-breaking contributions to the development of neutron scattering in the 1950s. In the 30 years following Brockhouse's pioneering work at Chalk River, his methods had been replicated and further advanced at major neutron sources around the world, enabling many areas of research in solid state physics. The selection of Brockhouse and Shull for the prize reflects the versatility and irreplaceability of neutron beams as scientific tools capable of providing insights about materials that other scientific techniques cannot offer.

THE NATIONAL RESEARCH COUNCIL YEARS – 1997-2013



NRC Neutron Program for Materials Research staff gathered at the N5 beamline at the NRU reactor in 2002.

In 1997, the operations of the neutron beam laboratory and its scientists were transferred to the National Research Council (NRC). This change reflected the fact that the lab's scientific user facility mission was better suited to Canada's national science organization than to AECL, which at that time was refocusing its efforts on its CANDU power reactor commercial business. The lab operated as the Neutron Program for Materials Research until 2005, when it was renamed the Canadian Neutron Beam Centre (CNBC) to better reflect its national mission.

Throughout the NRC years, the user community helped attract funds from NSERC and the Canada Foundation for Innovation to boost operations, providing excellent support for users and their experiments. The beamline capabilities were enhanced and a new neutron beamline was built: the D3 reflectometer, completed in 2007. The CNBC reached an operational peak around 2008, with its six beamlines highly subscribed by a user community of more than 700 research participants over a five-year period. These participants included users of all types, from students and post-doctoral researchers to industry and government scientists from across Canada and around the world. Over 50 scientific publications and technical reports were produced each year, and services to industry generated a cumulative $6 million in fee-for-service revenue from over 200 projects.

A DECADE OF FEEDER STUDIES FOR CANADIAN NUCLEAR POWER – 2001-2011

Two unexpected leaks in feeder bends at the Point Lepreau Nuclear Generating Station in New Brunswick in 1997 and 2001 resulted in costly outages. The CNBC played a critical role in the failure analyses, demonstrating that stress left by the manufacturing process was a major factor in producing the cracks. This discovery led to a decade of industry research to study the cracking mechanism, and the CNBC's stress-scanning capabilities were called on frequently for this research. The findings were applied to assure safety for relicensing and also to determine how to manage the scope of ongoing feeder inspection programs throughout the Canadian nuclear power industry. Paul Spekkens, Vice President of Science and Technology Development for Ontario Power Generation at the time, recently reflected on the CNBC's role in these industry advancements:

"Research using neutron beams provided critical knowledge needed by operators of power plants based on the CANDU design in Canada and abroad. Cracking detected in the feeder tubes at some of Canada's stations led to the need to inspect feeders across the CANDU fleet, resulting in additional downtime and dose in order to perform on-going inspections of the feeder tubes. The neutron beam analyses of residual stress were used to identify which manufacturing practices resulted in tubes that were susceptible to cracking, and where on the tubes the cracks would be located. This enabled inspection staff to focus their efforts and, in some cases, eliminated the need for inspections or reduced their frequency. This result led to public benefits in several forms: the radiation dose to inspection workers was significantly reduced by minimizing their time spent near the reactor face. Plant downtime was decreased while maintaining safety margins, resulting in financial savings. Power utilities in other countries using Canadian technology were provided knowledge to support the safe, reliable, and economic operations of their plants as well, thereby enhancing the cooperative relationships across the CANDU industry."

The impacts of this one line of research are estimated to be worth hundreds of millions of dollars to this country alone, exceeding all of Canada's direct investments in the neutron beam facilities at the NRX and NRU reactors since the 1940s.

A mock-up of a CANDU reactor face, revealing some of the many bends in a reactor's feeder tubes (shown here in black). (NA Engineering)

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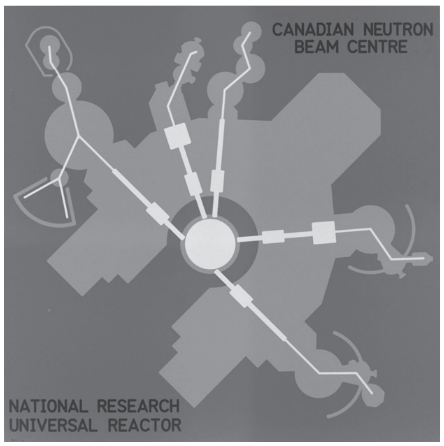
RUNNING STRONG TO THE FINISH LINE – 2013-2018



A neutron image (radiograph) of plates engraved with the layout of the beamlines around the NRU reactor. The image was taken with the final neutrons from the reactor.

Responsibility for funding and operating the CNBC was transferred back to AECL in 2013, and then to AECL's successor, Canadian Nuclear Laboratories, which was created in 2014 to operate all facilities at Chalk River Laboratories. In February 2015, the final shutdown date of the NRU reactor was announced. Despite the pending closure, the CNBC team strove to extract as much value and impact from the reactor as possible in its final years of operation. The user community remained strongly engaged, and research participants grew to nearly 800 in number in the final five years. All beamlines were collecting data until the very last moment of operation on March 31, 2018. Most of these beamlines were still performing among the best in the world. Among these high performers were a powder diffractometer, a polarized triple-axis spectrometer, a neutron reflectometer, and a stress scanning diffractometer. A memorial neutron radiograph was taken during the final minutes of the reactor's operating life, capturing the last neutrons exiting the reactor as it shut down.

THE NOBEL PRIZE IN PHYSICS – 2016

The 2016 Nobel Prize in Physics reflects the magnitude of the scientific impact of discoveries made by Chalk River scientists in the 1980s (see Discovery of Topological Materials). The 2016 prize was awarded to three physicists working in the US who had made predictions about materials using a branch of mathematics called topology. Neutron beam experiments conducted at Chalk River by Bill Buyers and others provided the first evidence that the mathematical theories were indeed valuable for describing real materials. These experiments overturned the wisdom of the day and led to the acceptance of topological theory, thereby opening the field of topological materials research—an area of study that has dominated frontline research in condensed matter physics for the past 20 years. Scientists now believe that topological materials might hold the key to realizing valuable technologies such as quantum computing, superconducting computing, and spintronic computing.

Bill Buyers contributed to research honoured by the 2016 Nobel Prize in Physics.

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CANADIAN NEUTRON BEAM CENTRE
Probing Materials for Science and Industry