Canadian Nuclear Association

NUCLEAR RESEARCH AND DEVELOPMENT IN CANADA

SUMMARY AND UPDATE

Canadian Nuclear Association
April, 2011
V4.0

EXECUTIVE SUMMARY

The Canadian nuclear industry is a substantial and integral part of the Canadian economy, generating over $6.6 billion a year in economic activity, over $1.5 billion in federal and provincial revenues, and over $1.2 billion in exports in 2008. The industry sustains 71,000 direct and indirect full time jobs.

The Canadian nuclear industry is also of immense strategic importance. Canada's CANDU heavy water reactor technology is unique and is found in electricity generation reactors around the world. The nuclear research conducted in Canada, principally at the Chalk River Laboratories (CRL) and at twelve universities that are members of the University Network for Excellence in Nuclear Engineering (UNENE), not only supports these made-in-Canada reactor technologies but is used by worldwide clients. It is a key component of Canada's science, technology and manufacturing infrastructure.

As in other advanced economies, Canada's federal government and the Canadian nuclear industry have a long history of investing in nuclear research, and with good reason. Nuclear R&D supports materials testing and product improvements, medical products and services, training and development of scientists and engineers, and other activities of high value to an advanced economy. It also supports Canada's ability to manage radioactive materials and to meet our international commitments with respect to nuclear security and non-proliferation. Most immediately, this research is fundamental to the safe operations of current nuclear reactors in Canada and abroad.

Investments in nuclear energy R&D are aligned with several key Government of Canada goals, notably: clean energy technologies to meet climate change goals; economic development and job creation (as outlined in the Economic Action Plan); and strengthening Canada's science and technology infrastructure. The Government's "Centres of Excellence for Commercialization and Research" program identifies nuclear energy as a priority area for support.

Given the strategic importance of nuclear research to the Canadian nuclear industry and to the broader Canadian economy, it is important that all stakeholders - including the Government - have a clear understanding of nuclear research activities, of the impact of ownership change, and of investments that may be necessary to support safe nuclear operations and to create economic opportunities in the future.

NUCLEAR RESEARCH AND DEVELOPMENT IN CANADA

The Canadian Nuclear Association (CNA) represents the entire Canadian nuclear industry – manufacturers of reactors that generate clean electricity, research and development facilities, materials testing services, medical isotopes and devices, uranium mining and processing, Canadian companies supplying materials and expertise to these sectors, and their 71,000 workers.

Canada has been a world leader in nuclear technology for over 60 years. Atomic Energy of Canada Limited's (AECL's) Chalk River Laboratories (CRL) has served as Canada's national laboratory for nuclear science and technology and provided the nuclear infrastructure and highly qualified expertise to support CANDU technology, materials science research and medical radioisotope development and production.

AECL employs approximately 5,000 staff and supports a scientific community of over 400 researchers and engineers from Canadian industry, government and academia. More than 200 academic researchers from at least 20 Canadian universities, involving over 50 different departments, use the CRL facilities that provide domestic and international benefits for Canada in reactor technology, materials science and medicine.

There are approximately 20 neutron scattering laboratories worldwide, supporting a diverse international scientific community researching materials for a host of applications that are essential to modern manufacturing. The National Research Council's Canadian Neutron Beam Centre (CNBC) at CRL is an active participant in that community; CNBC hosted international collaborative projects involving scientists from 100 institutions in 20 countries in a typical 5 year period.

Nearly all neutron sources in the world are publicly funded, and according to an NRC review of these facilities published in 2009, "The proportion of neutron scattering experiments conducted by the private sector [internationally] is generally low. By comparison, Canada's CNBC at NRU can be said to be reasonably successful, with 14% of its operating cost funded by proprietary research."[1] The reactor facility at Ecole Polytechnique de Montreal funds 100% of its operating costs in this way.

Canadian scientists benefit substantially from Canada's recognized capability in nuclear R&D when they do international work; it enhances their status at foreign neutron laboratories, helping them to share the resources and knowledge of international counterparts.

[1] National Research Council, "An international review of selected research reactors and neutron spallation sources," February 2009, p. 36. The review also concluded that "Canada's NRU reactor [at Chalk River, Ontario] is unique. NRU is the only neutron source, at least in the western world, that has extensive neutron scattering, isotope production and nuclear R&D capabilities. NRU has demonstrated that a single reactor can be internationally competitive in all of these areas" (ibid, p. 39).

HIGHLY QUALIFIED PERSONNEL IN SCIENCE AND ENGINEERING

Working R&D facilities, including (but not limited to) working reactors, are a key asset in developing highly qualified scientific and engineering personnel. These personnel do not necessarily begin in, or remain in, nuclear disciplines; rather, they may be primarily devoted to chemistry, metallurgy, materials engineering, health science, safety and accident investigation, or other areas in which knowledge of radiation and nuclear science is advantageous. They may work in the many industries that use radioactive materials or processes (notably health care); in regulatory agencies responsible for nuclear power, the environment, food safety and other areas; or in government policy relating to such diverse areas as energy, human and animal health, and international nuclear safeguards.

The **University Network of Excellence in Nuclear Engineering** (www.unene.ca) is a Canadian based alliance of a dozen universities plus nuclear power utilities, regulatory agencies and others who support the growth of nuclear education, research and development capability in Canadian universities. UNENE coordinates graduate level programs in nuclear science and engineering. UNENE's work ensures that the supply of highly qualified graduates in nuclear engineering and technology is sufficient for industry needs, that university-based research in these areas is vigorous, and that a group of university-based nuclear experts is available whenever they are required for industry and public consultations. These goals would be harder to attain if Canada lacked a full range of nuclear R&D facilities.

NUCLEAR R&D SUPPORTS OTHER STRATEGIC SECTORS IN CANADA

Research activities at Chalk River and at various universities and research reactors support many key sectors in their R&D and commercialization activities.

NUCLEAR R&D IN SUPPORT OF MATERIALS SCIENCE

Chemical studies using nuclear R&D have studied crystal structures of new materials for lithium-ion battery improvements, hydrogen-storage and fuel cells or coating for medical implants. Nuclear R&D can study how manufacturing processes affect materials at the basic level of crystal structure, looking for ways to make reliable materials cost effectively. Nuclear R&D also contributes to health sciences by studying nanostructures to design carriers for therapeutic agents that can target cancer, Alzheimer's disease and more.

Examples of industries that deal with advanced materials that benefit from access to neutron beams in Canada:

- **Pharmaceuticals and medical devices**
- **Environmental technologies**
- **Automotive fuel producers (including hydrogen storage and fuel cells)**

- **Producers of metals, composites and plastics**
- **Advanced electronics**
- **Food processing**
- **Electrical power distribution**
- **Advanced polymer producers**
- **Oil recovery**
- **Paint and adhesives**
- **Coatings for hardening of tools**

At the University of Saskatchewan, the Canadian Light Source (CLS) is Canada's national centre for synchrotron research. The CLS is a powerful tool for academic and industrial research in a wide variety of areas including environmental sciences, natural resources and energy, health and life sciences, and information and communications technology.

The CLS is similar to the Canadian Neutron Beam Centre (CNBC) in that it produces beams that are used to probe a wide range of materials. Neutron scattering and synchrotron radiation research will continue to be indispensable because the two techniques cannot replace each other (nor be replaced by third methods); indeed they complement and extend each other's range and opportunities. The CNBC and CLS are essential elements of a complementary suite of facilities needed for materials research.

IMPROVING RELIABILITY FOR AEROSPACE

Reliability is crucial in many components in aircraft engines, aircraft structures, rocket booster casings, and other devices for space applications. But these components should not be "over-designed" because reducing weight is also very important. In order to find the proper balance between weight and reliability, NRC-CNBC has used neutrons to probe materials to examine residual stresses in components from all over the aircraft structure: turbine discs, compressors and spools, landing gear, airframe structural components, hull skins, rivets, and fasteners. These projects involved the analysis of a wide range of alloys: nickel-based alloys, Waspaloy, titanium alloys, aluminum alloys and steel.

In the manufacture of components such as turbine blades for the aerospace industry, there can be zero tolerance for design fault or failure, since the consequences of failure would be catastrophic. Computer modelling of manufacturing processes, such as the welding of critical components, can help accurately predict when and where problems are likely to occur due to stress in the material. But computer models need to be experimentally calibrated and validated. Therefore, research teams including Cambridge University and Rolls Royce used NRC-CNBC to test their models on turbine blade parts and help them predict lifetimes of other aircraft components.

COMPUTER HARD DRIVES

Hard drives are the principal memory devices for computers. Hard drives use magnetic materials to store information, taking advantage of an effect called Giant Magneto-Resistance (GMR). Because neutrons are magnetic and have no electric charge, they are the only probe that can unambiguously determine certain magnetic properties of materials. Thus the study of the GMR effect was a hot area of research in the early 1990's at NRC-CNBC and other foreign neutron sources while hard drives were being developed.

NUCLEAR MEDICINE

Canada's nuclear infrastructure is essential to the global medical isotope supply. Nordion processes materials from AECL at the Chalk River Laboratories to produce 50% of the world's medical isotopes providing innovative technologies for medical imaging and radiotherapeutics and sterilization technologies. More than 65 countries around the world benefit from Canadian nuclear medicine technology including Canadian-produced medical isotopes for nuclear medicine used in over 50,000 procedures a day world-wide, with 5,000 in Canada alone.

HUMAN CELL GENETICS

In 1970, The Chalk River Laboratories began conducting ground-breaking research in human cell genetics, significantly advancing medical research programs around the world.

MEMBRANE RESEARCH

Pioneering biological research in understanding the role of cholesterol in membranes is taking place at Chalk River using the NRU.

OTTAWA HEART INSTITUTE

Nordion is collaborating with the University of Ottawa Heart Institute, Canada's largest cardiovascular health centre, to establish a Molecular Imaging Centre of Excellence to advance cardiology research. The new centre enables the two organizations to collaborate on joint cardiology research using the latest in molecular imaging technology.

MOLECULAR HOLOGRAPHIC IMAGING

An important application of neutron holography may enable molecular structure determinations for high resolution for membrane-associated proteins (about 1/3 of known proteins). Most membrane-associated proteins are difficult to fully crystallize and therefore have defied detailed characterization in all but a few examples. Such a capability would have a major impact on the understanding of protein structure and function for the life sciences.

COMMERCIAL STERILIZERS

AECL developed the first commercial sterilizers used to process medical, pharmaceutical and food products. Canada is a leader in the development of gamma technology used to eliminate food-borne pathogens such as harmful E.Coli and Salmonella. These technologies make food safer and serve as a quarantine treatment for fruits and vegetables to reduce post-harvest losses caused by spoilage, pest infestation and contamination.

NUCLEAR FUEL TESTING

Canadian research reactor fuel technology provides support for the fabrication of fuel for the NRU at Chalk River Laboratories; the development of next-generation research reactor fuels and targets; and the maintenance and upgrading of reactors.

With a renaissance in power reactor programs beginning around the world, it appears likely that research reactors will also experience a renaissance as well, and with it the need for new fuel products. Provision of suitable fuel testing capability in a new research reactor will not only ensure that emerging requirements will be met but may also open up major commercial opportunities in the future.

STRESSES ON CANDU FEEDER TUBES

Nuclear R&D can optimize manufacturing practices to enhance reliable service over prolonged lifetimes. An outage due to a cracked feeder could cost millions of dollars to repair or replace. The safe life extension of nuclear power stations is an important part of plans in Ontario, Quebec, and New Brunswick for electricity in the coming decades. Neutron diffraction can be applied to the investigation of residual stresses in feeders for CANDU nuclear reactors.

INDUSTRIAL RADIOISOTOPES

Industrial applications of radioisotopes were pioneered in Canada at the same time as medical applications. They benefitted from the same freedom of research and development that a large, flexible multi-purpose research reactor provides. In the industrial and mining sector, radioisotopes are now an essential tool for gauging material thickness manufacturing, sterilization, radiography, mineral analysis, flow and chemical reaction tracing, and environmental analysis.

STEEL MANUFACTURING FOR BRIDGE CONSTRUCTION

IPSCO, a major Regina based steel-maker, built the world’s largest temper leveling line in Scarborough that produces longer, wider and thicker steel plates from coils than previously possible. Historically the Canadian standards for bridge construction did not allow that steel to be used for bridges. A project at the NRC-CNBC demonstrated that internal stresses in the steel were acceptable, and thus opened up an important new materials advance for bridges in Canada. IPSCO advises there are 37,000 bridges needing construction work in Ontario alone and they are very pleased that this project opened that market to them.

REDUCING ENERGY CONSUMPTION IN THE PAPER INDUSTRY

Quebec is a big producer of sodium chlorate, a bleaching agent for the paper industry. Research into this area is of great importance to the Quebec paper industry. A scientist from Hydro-Quebec visited the NRC-CNBC to see if a clear understanding could be obtained about the role of oxygen in a nanocrystalline alloy that his group was developing as a cathode for the production of chlorates. The information obtained by neutron diffraction played a crucial role in the development of the new electrode material, which will reduce energy consumption in chlorate production by 10%, a savings of over $6 M per year in Quebec alone. The cost of operating the neutron facility to obtain the key information was only $20,000 - a one-time exploratory project that may revolutionize one niche of Canada's economy.

SAFETY FOR AIR AND RAIL TRANSPORTATION

Neutron radiography is a powerful tool to interrogate metals and components for reliability. Structural integrity of jet turbine blades is critical to ensure efficiency of engine turbine and safety of the passengers. Over 90% of all jet turbine blades worldwide are inspected for flaws using Canadian neutron radiography.

On Aug. 3, 2005, 43 cars of a 140-car CN freight train derailed along the north shore of Lake Wabamun, west of Edmonton. The derailment ruptured 12 of the cars, spilling about 730,000 litres of bunker C fuel oil and 88,000 litres of pole oil, a potentially hazardous wood preservative along the shore and into the lake. The spill affected wildlife and the local environment. Local residents were advised to avoid use of water for drinking, gardening or swimming. Suspect pieces of track recovered from the area where the trains derailed were sent to the Ottawa lab of the Transportation Safety Board (TSB) for metallurgical analysis.

Neutron diffraction is the only method for non-invasive mapping of stresses inside large components, and NRC's neutron stress-scanning facility is recognized to be the world's best. The TSB approached researchers from the NRC - CNBC to explore whether or not residual stresses, locked in from the time of rail manufacture or accumulated during repetitive loading in service, might be linked to fractures in the rails. NRC-CNBC showed that the residual stress field is perturbed near microstructural features called 'shells', suggesting that these may be precursors of the fractures.

NAVY SUBMARINE CAPABILITIES

Propelling large marine vessels is tremendously energy-intensive. The world's major naval powers (USA, UK, France, Russia, China, India) have used nuclear propulsion systems in submarines for decades because of their many operating advantages over diesel engines, especially over long ranges. Nuclear propulsion has also been used in icebreakers, tankers, and other large cargo ships. While Royal Military College has a research reactor and it has done significant research on marine drive systems, Canada does not currently use nuclear propulsion technology.

The British Navy transferred one of its last diesel-electric submarines to Canada in the late 1990s and this submarine is now known as the HMCS Victoria. A large dent in the sub's hull had to be cut out and a new piece welded in. As parts are very rarely removed from submarine hulls, this provided a unique opportunity for Defence Research & Development Canada to ask NRC-CNBC for non-destructive examination of the removed section, which contained a fabrication weld. The analysis was used to improve understanding of service inspection data and to improve computer models that predict the operational limits (e.g. ultimate dive depth) of submarines.

CONCLUSION: MOVING FORWARD

Research is critical to provide and maintain the foundation for Canada's international success as a leader in nuclear, manufacturing, medical and other technologies. It supports current CANDU nuclear reactors domestically and internationally by providing solutions to operational issues essential for safety, efficiency and productivity. Engineers, scientists, researchers and other skilled labour are attracted and retained as a result of access to operational research projects and research facilities including research reactors.

Universities with nuclear expertise and nuclear reactors could be linked to create the foundation for a Canadian Nuclear Network of Centres of Excellence. These institutions currently include:

- **Twelve university members of the University Network of Excellence in Nuclear Engineering (UNENE)**
- **TRIUMF in British Columbia**
- **Canadian Light Source in Saskatchewan**
- **Whiteshell decommissioning activities in Manitoba**
- **the Chalk River Laboratories in Ontario**
- **Pharmaceutical and aerospace research activities in Quebec; and**
- **UNB and Saint John Energy Hub activities in New Brunswick**

While the Centre of Excellence model is a promising one, it may not be sufficient to maintain the full benefits that can and should be obtained by Canada from nuclear research and development. A variety of models warrants examination.

Among these is the United States' Idaho National Laboratory, which is primarily funded by appropriations from the federal Departments of Energy, Homeland Security, and Defense. The U.S. Department of Energy has made a sustained effort to revitalize nuclear research and development in recent years, and funding to the system of National Laboratories has been a major route to this goal. Subcommittee markup of the 2011 energy appropriations bill notes that advancing nuclear science and technology assists U.S. economic competitiveness and will position the U.S. to help mitigate global climate change. The bill also supports various research initiatives for small reactor designs, and creates a Center of Excellence for Nuclear Waste Management.

Government should carefully consider its role in maintaining and supporting research infrastructure that supports broad economic and social objectives as well as pure research initiatives, as defined under its

Science and Technology Agenda. These and other research opportunities need to be more fully studied and understood before decisions on the AECL research components are taken.

A Strategic Review should be launched to bring together federal and provincial governments and industry stakeholders to examine the cluster of key nuclear economic opportunities. Decisions of this magnitude, with long impacts on many sectors in Canada and abroad, should consider with significant input by all stakeholders. A Strategic Review represents the most direct and effective way forward in the shortest time frame.

A separate CNA document, "A Strategic Review of Nuclear R&D in Canada: Selecting a Process" sets out CNA's thoughts on the possible purpose, structure, time frame and membership of a strategic review.

PUBLIC RESEARCH AND DEVELOPMENT INFRASTRUCTURE

"Other firms and segments of society benefit through spillovers as the knowledge spreads through research papers, patents, technology licenses, mobility of the workforce, etc. . . . **By intensifying R&D activity and broadening its R&D portfolio, government expands technology opportunities** and therefore increases the chances of a successful outcome."

(Bordt, Hamdani and Therrien, "Why conduct R&D?," Statistics Canada Innovation Analysis Bulletin, v.8 no.1, February 2006).

"The panel's analysis suggests the need for **proactive public policies to support areas of particular Canadian strength and opportunity through focused, sector-oriented strategies**, such as was done in the past in, for example, the automotive, aerospace and information and communications technology (ICT) industries."

(Expert Panel on Business Innovation, 2009, pp. 11-12).

NUCLEAR R&D

Private energy R&D shrank in Canada between 1993 and 2003, and the share of that **R&D devoted to nuclear technologies shrank** even within that shrinking field -- from 12% to 8% of energy R&D. In constant dollars, actual spending by private firms on nuclear energy R&D fell from $79 million in 1993 to $52 million in 2003. (Radu Chiru, "R&D for New Energy Technologies in the Private Sector," Statistics Canada Analytical Paper, Cat. No. 11-621-MIE, 2006)

"Total public sector energy R&D investments in Canada lag behind those of Japan, the United States, France and Germany. . . Overall, we feel that **there is a need for much stronger government investment**." (Report of the National Advisory Panel on Sustainable Energy Science and Technology)

MATERIALS TESTING

"Neutron radiography is a powerful tool for **non-destructive testing of materials** and finds numerous applications in industry and in material research . . . Strong neutron sources like **research reactors** and accelerator-based spallation neutron sources can provide intense neutron beams required for efficient and practical . . . examination of nuclear fuels, explosives, electronic components and engine turbine blades. Recently, neutron imaging has been used in new branches: fuel cell research, the study of objects from cultural heritage, geosciences and soil physics . . . and the real-time analysis of systems including fluid flow and/or moving components. With the advent of portable neutron sources, neutron radiography can also be employed away from reactors, opening up applications like checking for drugs and explosives concealed in luggage and cargo containers. . . . **There are only a few [research reactor centres] which are well developed and have advanced facilities . . .** "

("Neutron Imaging: A Non-Destructive Tool for Materials Testing," International Atomic Energy Agency Tecdoc 1604, 2008)

ADVANCED MATERIALS

"Clients from the **aerospace, automotive, energy and environmental sectors supply a material or fully manufactured part to test**, and NRC researchers use the Chalk River reactor to perform neutron scattering, analyze the diffraction and report the data. Such information helps to project the fatigue life of the part. One of the greatest advantages of the program is that NRC can perform tests **under realistic conditions** including high temperature (up to 2000 ºC), high electric or magnetic fields, high tensile or compressive loads, and during operation in hostile environments. NRC can combine a variety of testing conditions, as required. For example, we can apply a load to a sample while heating it to see how it performs in these conditions."
("Applied Neutron Diffraction for Industry," National Research Council Industry Brief, 2008).

MANUFACTURING INNOVATION

"**Manufacturers need to know the tolerances of new materials before using them** to manufacture products - particularly those related to public safety. And the new knowledge we can provide by neutron scattering techniques can also lead to innovative materials or fabrication methods that **enhance competitiveness**."
("Applied Neutron Diffraction for Industry," National Research Council Industry Brief, 2008).

"Advanced materials and the manufacturing techniques to make them can give our economy a competitive advantage for job growth. . . . **Materials developments** are invisible to users of technology, but **are at the heart of so many important advances**."
(Materials Research Society)

"A 'Materials Genome Project" can catalogue the properties of known materials and allow designers to better model potential devices, thus **accelerating product development**."
("A Manufacturing Renaissance for America?," Massachusetts Institute of Technology News, 2010).

PRODUCTIVITY GROWTH

Manufacturing is by far the economic sector that contributes the most to productivity growth. "Services can propel the economy only so far. **There is no substitute for making tangible, useful products**."
("A Manufacturing Renaissance for America?," Massachusetts Institute of Technology News, 2010).

LIVING STANDARDS

Productivity growth is the *only* basis for sustained advances in living standards.

While industry will pay fairly for research and development services, only government can maintain a country's core R&D infrastructure.