THE CANADIAN NEUTRON SOURCE: STRENGTHENING CANADA'S ISOTOPE SUPPLY AND R&D CAPACITY

BY RICHARD FLORIZONE AND DEAN CHAPMAN

Shutdowns of Canada's National Research Universal (NRU) reactor in 2007 and in 2009-10 have created a crisis in the global supply of medical isotopes. While this shortage of isotopes is a critical issue, Canada stands to lose much more if the NRU is permanently closed — as is planned for 2016.

Research reactors like the NRU are a key component of global research and development infrastructure. In addition to providing the medical isotopes currently in demand, they

- enable the research and development of new applications for isotopes and advance the frontiers of nuclear medicine;
- supply neutrons for research across a broad spectrum of disciplines — from material and basic sciences to industrial applications and medicine; and
- provide a platform for training and for research and development on fuels and components for nuclear power technologies.

Indeed, nations such as Australia, the Netherlands, Germany, Egypt and Jordan have recognized these benefits and invested in their own new research reactors.

Canada needs a new, multi-purpose research reactor to replace the NRU — a reactor that will secure the country's supply of medical isotopes and build on its historic strengths in neutron science and nuclear medicine.

The authors and the University of Saskatchewan are partners in a consortium to establish just such a facility — the Canadian Neutron Source (CNS) — based on Australia's recently commissioned OPAL reactor. Potentially located near Canada's only synchrotron (the Canadian Light Source) in Saskatoon, Saskatchewan, the CNS could synergize neutron and photon science in Canada, following the lead of other countries that have co-located their synchrotrons and research reactors.

SUMMARY

In this paper, the authors give a brief overview of the isotope crisis, outline the broader R&D benefits of a new multi-purpose reactor and summarize their proposal for the Canadian Neutron Source.

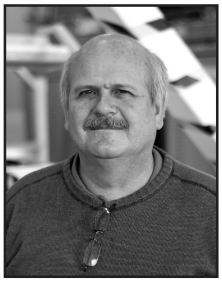
SOLVING THE ISOTOPE CRISIS

Canada's NRU reactor at Chalk River has historically provided 30-40 percent of the global supply of molybdenum-99 (Mo-99), the parent isotope of the short-lived technetium-99m (Tc-99m) used in millions of medical tests for cancer, heart and bone disease.

Canada's health care system relies on a stable supply of medical isotopes to diagnose and treat thousands of patients every day. Doctors use isotopes in nuclear imaging 30,000 times every week to quickly and accurately diagnose illness including many forms of cancer. They use isotopes for approximately 300 brachytherapy treatments (in which radiation from isotopes controls or eliminates cancerous growths) every week. As of 2016, Canada will need a new source of supply for these isotopes, and, if it wants the supply to be home-grown, it can choose between production using reactor-based or the newer proposed accelerator-based techniques.

The reactor technique relies on the neutron-induced fission of U-235, of which Mo-99 is a byproduct about six percent of the time. The Mo-99 is chemically removed from the U-235 target and absorbed into generators that are shipped to hospitals and clinics. When the Mo-99 decays (~66-hour half-life) into Tc-99m (~six-hour half-life), the Tc-99m is eluted or washed out with saline solution and used in the nuclear medicine procedure.

Accelerator-based techniques use high-energy electrons from linear accelerators or protons from cyclotrons to create isotopes. The former create high-energy gamma radiation from impinging the electrons onto a converter target. These gammas can be used to split U-238 or U-235 via photo-fission. This process has the distinct advantage of creating Mo-99 using either uranium isotope. Alternatively, the gammas can be used to transmute Mo-100 into Mo-99 by ejecting a neutron. The proton cyclotron approach utilizes protons striking a Mo-100 target to create Tc-99m. This direct conversion method would only provide a local supply of Tc-99m due to its



Richard Florizone*
<richard.florizone@usask.ca>, Policy Fellow, Johnson-Shoyama Graduate School of Public Policy, University of Saskatchewan,
105 Administration Place, Saskatoon SK
S7N 5A2

Dean Chapman
<dean.chapman@usask.ca>, Professor, Anatomy and Cell Biology, Canada Research Chair in X-ray Imaging, Univ. of Saskatchewan,
107 Wiggins Road, Saskatoon SK
S7N 5E5

---

* The authors and the University of Saskatchewan are partners in a consortium to establish the Canadian Neutron Source research reactor facility.

short half-life, and therefore, a single site would not supply the whole country.

In 2009, the Government of Canada convened an expert panel to compare these techniques and their advantages and disadvantages against specific criteria, namely: technical feasibility; business implementation; timeliness; regulatory issues; and benefits to Canadians. In its final report [1] dated November 2009, the report stated:

> *"We recommend that the government expeditiously engage in the replacement of the NRU reactor as we believe a multi-purpose research reactor represents the best primary option to create a sustainable source of molybdenum-99, recognizing that the reactor's other missions would also play a role in justifying the costs."*

In other words, this is a recommendation that the Government of Canada build a new, multi-purpose, research reactor as well as the expanded facilities for processing isotope targets made with low-enriched uranium. Even though this option is costly, it is the guaranteed, long-term solution to Canada's security of isotope supply, and furthermore offers the most associated benefits to Canadians in areas of enduring value — energy and materials research. The decision to invest in this key element of Canada's infrastructure for science and industry should be taken as soon as possible.

BEYOND ISOTOPES: STRENGTHENING CANADA'S R&D CAPACITY

Nuclear Medicine Training, Research and Development

Canadian scientists have pioneered a number of medical applications, such as the production and use of medical isotopes that began with the supply of cobalt-60 for nuclear medicine procedures. The result was the world's first cobalt-60 cancer treatment, which revolutionized cancer radiation therapy worldwide and greatly improved survival rates for people suffering from formerly untreatable cancers, including cancer of the bladder, prostate and cervix. Canada also introduced the use of isotopes for diagnostic imaging of disease and continued its leadership in nuclear medicine by supplying a variety of medical isotopes, including the previously mentioned 30-40 percent of the global supply of Mo-99, via the NRU reactor.

Nuclear medicine offers non-invasive imaging of biochemical changes in living organisms that is not possible with other imaging modalities. Isotopes can reveal how organs and bodily systems are functioning, not just what they look like, as with X-rays. This is key to tracking the progress of disease and the effectiveness of drugs, as well as reducing exposure to ineffective and possibly toxic treatment. Current applications include diagnosis of diseases such as cancer, neurological disorders and cardiovascular disease at early stages, enabling earlier treatment. Applications have grown to include visualizing intracellular processes, enzyme trafficking and receptors, and gene expression.

Canada must continue to innovate and develop new applications through leading-edge research to stay ahead of evolving treatment and diagnostic needs. Particularly exciting is the promise of delivering molecularly targeted treatments for some cancers and endocrine disorders, leaving healthy cells alone. The use of isotopes and the imaging technologies around them is creating the opportunity to individualize treatment and medication based on a person's unique genetic profile and response to disease (personalized medicine).

Shortage of nuclear medicine scientists

Aging facilities and a shortage of nuclear medicine scientists and clinical personnel are hampering the advancement of nuclear medicine and critically important research in Canada. The declining number of reactors in North America since the mid-1970s has limited research into new radiopharmaceuticals and reduced opportunities to train highly qualified personnel in preparing therapeutics. There is now a shortage of clinical and research personnel in all aspects of nuclear medicine that has affected the ability of universities to provide training. Canada needs to act now to revitalize its capacity for neutron-based science and train the next generation of nuclear medicine scientists and practitioners.

The need for both highly qualified personnel and research facilities argues strongly for linking new isotope-generating reactor facilities with a university — ideally, a national centre for nuclear research and training which would promote the training of undergraduate and graduate students, as well as post-doctoral fellows.

NEUTRON SCATTERING CHALLENGES AND OPPORTUNITIES

Arguably, Canada invented neutron research in the 1950s when National Research Council (NRC) researcher Bertram Brockhouse realized that these particles could be used to provide completely new insight into matter — a discovery for which he shared the Nobel Prize in 1994.

Due to their uncharged nature, neutrons can penetrate deep within materials without damaging them to reveal their structure and dynamics. This property makes neutrons the probe of choice for investigating stress in large objects and for characterizing the molecular and atomic-level structure and behaviour of materials ranging from metals and ceramics to plastics and blood. The ability to easily exchange energy with the nuclei of materials provides insight into the dynamics of systems.

Neutrons are sensitive to differences among isotopes of elements and can reveal structural information that cannot be

---

1. "Report of the Expert Review Panel on Medical Isotope Production," Presented to the Minister of Natural Resources Canada, 30 November, 2009. Available for download at: http://nrcan.gc.ca/eneene/sources/uranuc/pdf/panrep-rapexp-eng.pdf

gained through X-ray or other techniques. For instance, hydrogen is very difficult to see with X-rays because it contains very little charge and so is nearly invisible to the X-ray photons. However, deuterium has a significantly different neutron signature than hydrogen, which allows one to "see" the water-hydrating protein molecules that are key to investigating biological systems such as membranes, protein-protein interactions and DNA/protein complexes — knowledge that provides important clues into disease processes and how to treat or cure disease.

Neutrons can be "polarized" to investigate magnetic properties of materials, something very difficult to do with X-rays. This is important for basic research and industrial applications, such as development of materials for next-generation information storage on hard drives. As well, neutron sources can replace conventional thermal or ion-implantation methods for silicon doping electronic components and is emerging as a major advance in "green electronics."

As the national centre for neutron beam research through the NRC's Canadian Neutron Beam Centre (CNBC), the impending loss of the NRU reactor will have a significant impact on the research community, threatening the research of hundreds of scientists who will be forced to move their programs abroad. This would be a tremendous loss of Canadian expertise. The CNBC provides domestic and foreign scientists with specialized facilities to obtain new understanding of materials, improve products and services, and conduct research that supports the growth of Canadian industry and solves national challenges in health, climate change, the environment, clean energy and other fields.

To complicate matters further, as researchers expand the range of applications, the fewer than 45 neutron beam laboratories worldwide are increasingly oversubscribed.

Canada risks falling behind internationally in neutron research capability. Other nations have made continuing commitments to neutron science: Australia has just completed the OPAL reactor; in Europe the European Spallation Source is to be built in Lund, Sweden; the Netherlands completed the conceptual design and vendor pre-selection of a new research reactor; and other countries, such as the United States and Japan, are investing heavily in new, advanced neutron sources.

However, Canada has its own opportunity. Coupling a research reactor that delivers medical isotopes with a state-of-the-art neutron beam facility could maintain and restore its historical lead in neutron and medical research, and meet the demand for neutrons that will give the nation a competitive edge in basic science, medicine, materials and industrial innovation.

The Canadian neutron scattering community — well organized through the Canadian Institute for Neutron Scattering (CINS), which represents 15 organizational members from industry, government and academia — supports the call for a new reactor. CNIS's long-term planning culminated in the 2008 document, Planning to 2050 for Material Research with Neutron Beams in Canada, which calls for a world-class facility to address the three missions — reactor development and production of both isotopes and neutrons — that the NRU now fulfills.

This vision — to deliver medical isotopes while strengthening Canada's R&D capacity — is the driving force behind a joint proposal by the Government of Saskatchewan, the University of Saskatchewan and their partners for a new multi-purpose research reactor, the Canadian Neutron Source.

THE CANADIAN NEUTRON SOURCE

The Canadian Neutron Source (CNS) is a joint proposal of the Government of Saskatchewan, the University of Saskatchewan and their partners to build a new 20-megawatt, low-enriched uranium (LEU) research reactor facility, optimized to serve two purposes:

1. delivery of medical isotopes — specifically, with a preliminary goal of 2,000 six-day Curies of Mo-99 per week (or about one-sixth of global demand) to serve the Canadian and export market; and
2. delivery of neutron beams for neutron science — to serve the needs of Canadian science in industry and the public sector.

The focus on only these two missions — which excludes a potential third mission to support R&D on fuel for nuclear power generation — is a deliberate choice to minimize cost and technical risk. Accommodating R&D on nuclear fuel is important but would require a larger reactor core, which would significantly increase costs and represent a marked departure from the proven OPAL design on which the CNS is based (see Figure 1).

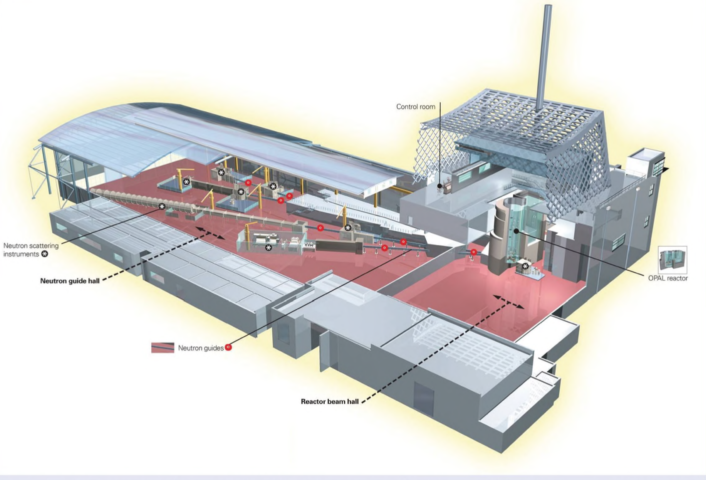


Fig. 1 Cut-away view of the OPAL reactor facility. This dual purpose (medical isotopes and neutron research) facility is similar to the proposed Canadian Neutron Source.

The CNS proposal has the support of over 20 scientific, medical, business and community organizations, each of which have provided a letter of support. These organizations are local, provincial, national and international, and include the Saskatchewan Cancer Agency, the Saskatchewan Health Research Foundation, the Canadian Light Source (CLS), Cameco Corporation, MDS Nordion, the Canadian Institute for Neutron Scattering (CINS), the Bragg Institute (Australia), and Institut Laue Langevin (France).

The Australian OPAL research reactor (see Figure 1) on which the CNS is based is a multi-purpose reactor capable of meeting the dual mission of the CNS. It is a proven design, minimizing technical risk. It uses low-enriched uranium to minimize the risk of proliferation, and it aligns with global efforts at phasing out highly enriched uranium in research reactors.

The consortium estimates total project development and construction costs at between $500 million to $750 million, the majority of which will come from the federal government and the remainder from the Saskatchewan government. Operating costs are expected to come from a partnership between federal and provincial governments and industry (isotope sales and industrial science).

As the expert panel recommended, the federal government must act quickly to minimize any gap between the permanent shutdown of the NRU and the start-up of a new reactor. The next most important milestone in the process is for the federal government to commit to the project — to develop a national policy around a new reactor — since its scale and complexity preclude Saskatchewan's provincial government from going ahead alone. Ultimately, the completion date (see bullet on Timeliness below) will depend upon a range of factors, including time required to secure the commitment of funding partners, the environmental and regulatory review process and the completion of public input processes. This timeline is based on initial conversations with the Canadian Nuclear Safety Commission (CNSC) and several partners.

Harnessing photons and neutrons to probe matter

Locating a facility that delivers medical isotopes and neutrons adjacent to Canada's newest, largest photon research facility — the CLS synchrotron — would create a synergy found in only a few places in the world.

The potential to apply neutron science to biomedical research and structural biology is recognized internationally as an emerging area for deeper understanding of the molecular basis for health and disease. The complementary application of photon and neutron techniques is probing the frontiers of science at the interface of chemistry and biology and has motivated the international community to promote the co-location of the next generation of synchrotrons and neutron sources.

Co-locating the proposed CNS on the University of Saskatchewan campus with the existing CLS synchrotron would create the synergistic research environment to pioneer novel approaches to issues of human health and treatment of disease. Furthermore, synergistic neutron/photon research in structural biology and in the study of soft matter is at the cutting edge of innovation in molecular biology, biotechnology and nanomaterials. The emerging international calibre excellence in research in medical imaging, diagnostics and therapy at the CLS would be significantly enhanced by complementary research into radioisotope applications.

The collaborative research and partnerships that would grow from co-location research synergies would lead to other new joint facilities that benefit the CNS and CLS. These could include biological preparation laboratories, crystal preparation facilities, metrology labs, advanced instrumentation and data collection collaborations, common data storage and visualization and detector development. The synergies of co-location would promote high-calibre science and attract world-leading scientists.

CONCLUSION

With the planned shutdown of the NRU in 2016, Canada stands to lose its domestic source of medical isotopes, weaken its capacity in nuclear medicine and lose its historic leadership in neutron science.

Two categories of technology (reactor- and accelerator-based) exist to produce substantial quantities of medical isotopes. The authors agree with the key finding of the Natural Resources Canada Expert Panel on Medical Isotope Production, namely that a reactor represents the best primary option for producing Mo-99 and offers the most associated benefits to Canada.

Canada needs a new research reactor. The authors believe that the CNS is the facility that best meets this need because it addresses the issue of a secure supply of medical isotopes and also supports the R&D opportunities of neutron science. Furthermore, with a proposed location near the CLS and the University of Saskatchewan, the CNS would be ideally suited to exploit the synergies between photon and neutron science, and to train the next generation of nuclear medicine professionals.

ACKNOWLEDGEMENTS

The authors acknowledge the advice of those individuals they drew upon in the writing of this paper and the contribution of the many people and organizations that provided information and support to the Expression of Interest[2] submitted by the Government of Saskatchewan and University of Saskatchewan to Natural Resources Canada Expert Review Panel on Medical Isotope Production.

---

[2] "The Canadian Neutron Source: Securing the Future of Medical Isotopes and Neutron Science in Canada", submission to the Natural Resources Canada Expert Review Panel on Medical Isotope Production, July 31, 2009.