CINS CANADIAN INSTITUTE FOR NEUTRON SCATTERING

Submission to the Expert Review Panel on Medical Isotope Production

"The Canadian Neutron Centre"

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ICDN INSTITUT CANADIEN DE LA DIFFUSION DES NEUTRONS

Summary

The Canadian Institute for Neutron Scattering responds to the public call for Expressions of Interest for the Expert Review Panel on Medical Isotope Production. Representing over 500 researchers from industry and academia, we offer our vision of an orderly replacement of the NRU reactor at the Chalk River Laboratories.

The centrepiece of our plan is the construction of the "Canadian Neutron Centre" (CNC), a reactor-based neutron source with associated laboratories and infrastructure. This world-class laboratory will surpass the ageing NRU reactor in each of its functions, namely (1) the production of medical isotopes, (2) nuclear energy R&D, and (3) the production of neutrons for materials research. As an important component of Canada's infrastructure for science and industry, the CNC will serve broad scientific, technological and health needs of Canadians for the coming decades.

The full plan lays out the requirements and priorities of the scientific community for Canada's new neutron source from the perspective of materials research using neutron beams. This plan was originally published in 2008 as *Planning to 2050 for Materials Research with Neutron Beams in Canada*. It was the result of a consultative and democratic process and is the culmination of the work of CINS members since the early 1990s.

We hope that the Canadian Government rapidly establishes a steering committee of stakeholders, and provides it with the funding and mandate to make this new national facility a reality.

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Introduction

The Canadian Institute for Neutron Scattering (CINS), represents researchers and students from universities and industries who need access to neutron beams to support their research programs. There are currently more than 500 individual members, and 15 fee-paying institutional members, predominantly Canadian universities. Our goals are to promote use of neutron beam methods for materials research and to represent the interests of the Canadian neutron beam user community.

In 2008, CINS published our vision for the future as "Planning to 2050 for Materials Research with Neutron Beams in Canada"[1]. In this document we proposed the construction of the "Canadian Neutron Centre", a new, multi-purpose research reactor facility that would replace the ageing National Research Universal (NRU) reactor at Chalk River, support all of the communities that currently use NRU, and represent a major national investment in research infrastructure for science and industry.

- Irradiation facilities and hot-cells would allow commercial producers of medical and industrial isotopes to supply these key commodities to Canadian and international markets, and also permit Canadian researchers to continue to develop new isotope products.
- The world-class neutron beam facility that would exploit the intense flux of thermal and cold neutrons that could be drawn from the reactor core would contribute to Canada's industrial and scientific competitiveness.
- The in-core facilities at the CNC would enable critical materials development that will be essential for Canada to continue in a leadership role in the international Generation-IV reactor program. They would also support orderly stewardship of the CANDU power reactor fleet that operates around the world.

[1] http://www.cins.ca

The extended shut down of NRU due to a heavy water leak has again focused attention on the essential roles played by this remarkable facility in the areas of nuclear engineering, health-care, industrial development and fundamental research. Canada and Canadians have enviable reputations in all of these fields, but if we do not commit soon to replacing NRU with a new multi-purpose facility, we stand to lose out in all of these areas. Only a research reactor could support all of the missions currently carried out at NRU.

The National Research Universal (NRU) reactor

The National Research Universal (NRU) reactor, located at the Chalk River Laboratories site in Ontario was the most powerful reactor in the world when it went critical on November 1, 1957. Its large core and inherently flexible design was intended to permit NRU to support a very wide variety of research, development, and production missions, a function that it has performed with great reliability for over fifty years.

In doing so, it has enabled generations of Canadians to express their talents and creativity:

- contributing to the establishment and operation of a domestic nuclear power industry that produces a substantial fraction of Canada's electric power with no greenhouse gas emissions;
- the creation of an international medical isotope business that contributes to the health of tens of thousands of Canadians every year, and millions more around the world;
- an industrial isotope business that provides for food irradiation, gamma and neutron imaging, and tracer analysis;

- the development of ground-breaking neutron beam techniques (e.g. Brockhouse's triple-axis spectrometer and the engineering stress-scanner) that have now been replicated at essentially every neutron beam facility around the world;

- contributions to industrial reliability and competitiveness by testing of engineered components (welded, forged, rolled, damaged...) and qualification of production practices to enable materials manufactured by new processes to be adopted into general use.

The historical context

The narrowing of AECL's business focus during the 1990's had a clear and negative impact on the utilisation of NRU as a multi-purpose research facility; its position as a major item of infrastructure for science and industry was degraded, and activities that were not directly related to the nuclear power industry were terminated.

The world-class nuclear physics program based around the tandem accelerator (TASSC) was scrapped, a number of commercial in-core activities (e.g. transmutation doping of high-purity silicon for the electronics industry) ended, efforts were made to off-load the medical isotope business via the now abandoned MAPLE program, and the neutron beam program was shut down.

The national out-cry from the Canadian scientific community in response to this last decision led to the rescue of the personnel and equipment by the National Research Council (NRC) and the re-establishment of the Canadian Neutron Beam Centre (CNBC) as a part of the NRC with both A-base funding from NRC and a Major Resource Support (MRS) grant from the National Sciences and Engineering Research Council of Canada (NSERC).

Future prospects

Many of these important, but abandoned missions could be revived at a new facility and a great number of new ones could be developed and added. Some of these would be commercial enterprises, and revenues from these activities could largely off-set the operating costs of the facility. Some examples drawn from recent developments at neutron labs around the world include; transmutation doping, industrial tracer isotopes, gamma and beta sources, topaz colouring, chemical trace analysis, and neutron imaging. Revenues from medical isotopes, however, are expected to continue to contribute the majority share.

A key feature of the CINS plan "Planning to 2050 for Materials Research with Neutron Beams in Canada" is a governance structure that ensures that the facility is operated as a research facility, rather than a business interest, with the access needs of all users being properly balanced. The CNC is envisioned as a major component of Canada's national science infrastructure, put in place by the Government of Canada and operated by Canadians in support of Canadian science and industry for the benefit of Canadians.

By establishing the CNC as a science and engineering facility that is open to all Canadian researchers, whether they be from government, industry or academia, we would be providing a platform for the generation and refinement of ideas. The facility would have a mandate to educate Canadian researchers, and to support and promote the uses of neutron-based techniques in research and development. The facility staff would provide active connections between the academic and industrial users that they worked with, facilitating the transfer of knowledge between fields of research and domains of application, with the development of new intellectual property, allowing Canadians to lead progress in both industrial and fundamental research. We see the CNC as a natural continuation of the Canada Research Chair program that attracted highly qualified people to Canadian universities. By providing a world-class multi-purpose user facility in support of science an industry, the CNC would enable the newly recruited talent to more fully express their creativity and would continue to attract new researchers to Canada.

Why is a nuclear reactor needed for medical isotope production?

The primary medical isotope of current concern is ^{99}Mo, known as "moly-99". This and several other important medical isotopes, including ^{60}Co, ^{131}I and ^{133}Xe, is a neutron-rich isotope most efficiently produced in a nuclear reactor. By contrast, the proton-rich light element isotopes used in PET (positron emission tomography) scanning (e.g. ^{11}C, ^{13}N, ^{15}O and ^{18}F) are most efficiently produced in small (20–30 MeV) proton cyclotrons.

^{99}Mo is generally produced by fission of ^{235}U (usually in the form of highly-enriched Uranium "HEU" targets to minimise the waste stream) and ^{131}I and ^{133}Xe are readily extracted by-products of this process that can be used to provide an added-value for ^{99}Mo production facilities. While other production routes for ^{99}Mo are possible,[2] none has yet been demonstrated on anything close to a useful production scale. Most would rely on technologies that are at best experimental. They have not been tested for feasibility, and all suffer from greatly reduced production rates, since the reaction cross-sections are typically factors of hundreds or thousands smaller than occurs in a nuclear reactor with neutron-stimulated fission. [3]

Production of ^{99}Mo by thermal neutron fission of ^{235}U is a proven technology that has been in commercial use for several decades. While some variations exist in the details of target design and extraction chemistry, this is a mature, well-understood technology with no surprises or significant risks associated with production or acceptance by pharmaceutical manufacturers. This situation stands in stark contrast to proposals to use photo-fission at electron linacs (the so-called "accelerator option"),[4] which would demand a 10–15 year research and development program to reach the stage where actual feasibility testing could begin, and even the most optimistic assessments[5] show that a large fleet of advanced high-power electron linacs (10–20 units) would have to be constructed in order to match the isotope production capacity of a reactor facility like NRU.

In addition, both the capital and the operating costs would be far higher than for a reactor with comparable production, and accelerators would be a dead-end, single-product solution, unable to support the diversity of missions carried out at a multi-purpose research reactor. (An evaluation of this "accelerator option" carried out by CINS members is appended to this submission.)

Reactor-based production of ^{99}Mo appears to be the best option currently available, and as we will go on to show here, the construction of a new, multi-purpose research reactor facility, with medical isotope production as one of its core missions will bring a wide variety of benefits in support of science and industry to Canada.

Why build a new multi-purpose research reactor facility?

NRU is far more than the world's largest single supplier of medical isotopes. It is a critical piece of infrastructure that supports stewardship and innovation in the nuclear power industry through experimental facilities located inside the core of the reactor. Neutron beams, emitted from the reactor core, support Research and Development by Canadian universities and industry. The unique knowledge obtained by neutron beams helps companies to develop more competitive products that are safer, more reliable and less expensive to manufacture.

The NRC's Canadian Neutron Beam Centre has established Canada as the worldwide leader in providing access to industry from key sectors: nuclear, aerospace, automotive and manufacturing. The CNBC also provides competitive facilities to support fundamental and applied research in many important areas: physics, chemistry, materials science, green energy technologies, communications and materials for the life sciences.

Consider what has been achieved during NRU's fifty year history:

- Medical isotope production in NRU has supported the health and well-being of Canadian Citizens: for both diagnosis and treatment of heart disease, bone disease and cancer.
- Engineering research at NRU has supported Canadian industry, both nuclear *and* non-nuclear, improving competitiveness and opening new markets to Canadian products.
- The research facilities at NRU have been used by thousands of Canadian engineers and scientists, training generations of Canadians who have added to the knowledge base of our industries and universities and raised Canada's profile as a technology leader around the world.

The infrastructure for science and industry that the Government of Canada provided at Chalk River was an investment in Canadians, that enabled Canadians to innovate and lead. This is what the Government of Canada does best, and this is what we need to do now.

[2](e.g. neutron capture by naturally occurring ^{98}Mo, various proton-induced reactions such as $^{100}Mo(p,2n)^{99m}Tc$ or $^{100}Mo(p,n)^{99}Mo$, and even photo-fission of ^{235}U or ^{238}U)

[3]See for example: "Medical Isotope Production Without Highly Enriched Uranium", National Research Council (2009) ISBN-10: 0-309-13039-5

[4]See "Making medical isotopes: Report of the Task Force on Alternatives for Medical-Isotope Production" TRIUMF 2008. `http://admin.triumf.ca/facility/5yp/comm/isotope-task-force.php`

[5]Ibid.

Every industrialised nation has found it to be essential to have neutron beam research facilities and the need continues to grow. As some ageing facilities are retired, others are refurbished and new facilities are being built. Britain is upgrading ISIS, the most successful pulsed neutron source to date. France has two research reactors, and the Millennium Project at the ILL in Grenoble represents a major upgrade that will ensure that this facility remains the international gold-standard for research reactors for the foreseeable future. In the US, their main reactor facility at NIST is slated for a major upgrade in 2010 that will nearly double its capabilities, and the upgrade for the newly opened $1.4B Spallation Neutron Source in Oak Ridge is planned now, even as the original facility is just coming on line.

Australia, Korea, Switzerland, Japan and Germany all have thriving facilities. China is opening its first neutron beam facility this year, and will complete its second in 2016 – **the same year we expect to retire our only research reactor.**

What do we lose if we walk away from NRU?

1. We abandon over fifty years of Canadian leadership in nuclear science and technology.

ZEEP was the first reactor ever built outside the US. It provided critical data for both the American and Canadian reactor programs and led to the construction of NRX, and a few years later NRU. When it was completed, NRU was the most powerful nuclear reactor in the world. It was big, effective, and most importantly flexible. It was built as a platform to enable research with neutrons and fifty years later it continues to support world-class research – a strong testament to the vision and abilities of its designers!

The flexible design has proved to be a key feature, as almost all of the activities currently supported at NRU did not exist at the time it was being built. There was no nuclear power industry, the medical isotope business was about to be created, and neutron beam research was in its infancy, limited by weak sources. In-core research at NRU supported the development of the nuclear power industry in Canada by enabling fuel and component testing in realistic conditions. It continues to contribute both to the stewardship of our CANDU fleet and to the development of next generation reactor designs.

The large flexible core permitted many materials to be irradiated, leading to the production and exploitation of a wide variety of isotopes most notably ^{60}Co and ^{99}Mo. The isotope business was invented in Canada, at Chalk River. Radiation treatment with Cobalt-60 from the NRU reactor was ranked number 11 on CBC's "Greatest Canadian Inventions", and today 16 million radiation treatments per year depend on ^{60}Co that is produced in the NRU reactor.

2. We abandon the legacy of Nobel laureate, Professor Bertram Brockhouse.

Neutron beam research facilities at Chalk River allow Canadians to study new materials, such as:

- High-Tc superconductors that offer the promise of zero-loss electrical power transmission,
- hydrogen storage materials and battery electrodes that will enable more environmentally friendly uses of power,
- high-strength super-alloys and composites that will revolutionise manufacturing in the future.

Canadians also use the neutron beams to study "old" materials in new ways. For example, most of our infrastructure is made of concrete. A better understanding how concrete cures, or how to control its nano-scale pores to make it more resistant to frost cracking, will provide billion dollar impacts on the reliability and lifetimes of our buildings and transportation systems.

Neutron beams from the NRU provide new knowledge on how to reduce the stresses in welded components, how to eliminate distortion when machining forged metals, how to minimize stress-corrosion cracking, and how to detect material weaknesses before a critical part fails.

By providing Canadians with the best neutron source in the world, the Government of Canada invested in Canadians and opened the door to innovations. Bertram Brockhouse was awarded the 1994 Nobel Prize in Physics for his development of the triple-axis spectrometer, an indispensable tool in the study of magnetism, superconductors and other materials. Similarly, the engineering stress-scanner was developed at Chalk River in the mid-1980s, and is critical to the study of stresses and strains in cast and machined parts for industry. Notably, all of the larger, foreign neutron facilities now have several copies of both of these instrument types.

3. We abandon many highly qualified and skilled persons of Canada.

Closing NRU is not really about leaving the isotope business to the private sector, it is about abandoning skilled and creative people. While the infrastructure provided by the Government of Canada enabled all of NRU's achievements, it was the people who brought their imaginations to the flexible, powerful NRU reactor and found a platform to refine their ideas into materials, products and benefits to science and society. Today, researchers still come from around the world to work at NRU even though it is not "the most powerful" reactor, and certainly not because it is the newest.

They come in large part because of the people. The excellence of the technical and scientific environment provided by the NRC's Canadian Neutron Beam Centre has been consistently recognised by NSERC and has stood up to review by panels of international experts. Researchers can do things at Chalk River that could not be attempted at other facilities, because of the stimulating environment the staff provide. This stimulating, multidisciplinary environment has been essential to our colleagues in CINS, who bring teams of graduate students and post-docs to NRU where they get hands-on training by experts in neutron beam techniques, and where they meet and exchange ideas with researchers from around the world.

These are the next generation of Canadian researchers, but if NRU is not replaced, where will they work?

When the Challenger space shuttle failed during launch, investigators focused their attention on the solid fuel boosters. One possibility was that stresses at the joints might have led to the failure. Even with neutron beam engineering stress-scanners available in the US, Thiokol, the NASA contractor who built the boosters, brought a booster section to Chalk River for evaluation. NASA came to Canada, to NRU, for the people and the expertise they needed – quality of service trumps any national bias. As Julie Payette travels to the international space station, everyone at NRU can take pride in knowing that they contributed in part to her safe trip.

4. We lose Canada's leadership in medical isotope development and supply.

The world loses a major source of medical isotopes and the gap left by NRU would not soon be filled. No new isotope production facilities are currently planned. Saskatchewan's "Uranium Development Partnership" recently concluded "the economics of a standalone isotope reactor are not attractive" so it is not clear where new supplies might be found. [6]

So what happens if the Government announces the closure of NRU in 2016 without making a firm commitment to build a replacement research reactor?

- The Canadian Neutron Beam Centre would be gone within a year of the announcement. With no future at NRU and no new research reactor to replace it, the staff would have no reason to stay. They would move to foreign laboratories and be lost to Canada. This would have immediate impacts on Canadian neutron beam research in both industrial and academic settings as access was lost and expertise evaporated. Fifty years of innovation and leadership would be abandoned.

- Canadian industry would lose its access to a key engineering materials evaluation facility, affecting product reliability and competitiveness.

- Canada would be unable to participate effectively in the international Generation-IV reactor development program that is tasked with creating the new higher-efficiency reactor designs and fuel cycles that will be so sorely needed if we are to reduce our dependence on carbon-emitting fossil-fuels for our power generation.

- All areas of science would be impacted, and Canadians' ability to fully participate in technological developments would be degraded. It is very easy to buy old technology, but if you are to understand and develop new technology you have to be engaged in forefront of science and engineering.

What should be done?

The role of government is to provide infrastructure for science and industry that will enable Canadians to carry out research and develop their businesses. In 1994 the Bacon report (commissioned by NSERC) recommended that "Canada should make an immediate commitment to develop a new fully equipped reactor-based national source for neutron beam research". The need for neutron facilities has not diminished. We at the Canadian Institute for Neutron Scattering proposed last year in our report "Planning to 2050" that Canada should build the Canadian Neutron Centre, a new multi-purpose research reactor that will serve Canadians as a key piece of infrastructure for science and industry.

The multi-purpose concept builds on the successes of NRU and is aimed at drawing together all of the

[6] "Capturing the full potential of the uranium value chain in Saskatchewan", Uranium Development Partnership, March 31, 2009. `http://www.saskuranium.ca`

current stake-holders while maintaining the flexibility to serve new and emerging needs. By combining in-core research facilities for nuclear engineering, with high-flux irradiation sites for isotope production and beam-tubes for world-class neutron beam instruments, the Canadian Neutron Centre would support a wide range of industrial and research activities. Industrial users would be able to build their businesses around the facilities offered, obtaining services on a realistic, full cost-recovery basis, so that revenue from these activities could be used to offset the operating costs of the facility.

A new world-class facility would be a magnet for talented engineers and scientists. Our continued leadership in nuclear engineering and neutron based research, both fundamental and applied, would be assured. A stable, reliable source of medical and industrial isotopes would be put in place.

Why embark on an expensive project in a recession?

Construction of the Canadian Neutron Centre is about building for the future. It is forward-looking, investing in new industries, training the technical and scientific leaders of tomorrow.

As a stimulus project it is a perfect fit. The construction phase would employ thousands of Canadians directly and generate many more jobs through the contracts awarded to small and medium-sized enterprises (SME) across Canada. A large fraction of these would be in high-value-added engineering projects that would expand Canada's design and manufacturing base in an industry that is poised for massive market growth. As most of the labour, expertise and materials would be Canadian-sourced, the Government could reasonably expect to recover a significant fraction of the capital outlay as the project was being built. Much of the work would involve high value added items such as reactor components, instrumentation hardware and control systems. The skills and capacity developed by Canadian SMEs as they contribute to the CNC would enhance Canada's design and manufacturing base in high-technology industries. Canada would be better prepared to take advantage of the coming demand for nuclear power generating stations. The increased economic capacity would lead to creation of new long-term employment areas in the Canadian economy.

In the fifty years that NRU has operated, is has led to the creation of medical and industrial isotope businesses; supported the development and operation of the CANDU nuclear power industry; neutron beam research has enabled Canadian industry to improve materials, develop and qualify new manufacturing techniques, understand welding in more detail, investigate stress management in materials. This work has broad economic impacts across Canada's economy: transportation infrastructure (bridges and railways), aerospace, oil and gas pipelines, automotive, power generation, manufacturing. Fundamental research using the neutron beam instruments around NRU have allowed Canadians to make internationally recognised contributions in instrument development, new materials and knowledge. The benefits to Canada from the work done in NRU run to billions of dollars, and greatly exceed both the initial capital investment made fifty years ago and the operating costs incurred since.

By returning to the original vision of NRU, the CNC will re-energise Canadian use of neutron-based techniques in science and industry, leading to substantial new economic impacts for decades to come.

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Project Description

We at the Canadian Institute for Neutron Scattering believe that the best long-term strategy for ensuring a stable supply of neutron-rich medical isotopes like ^{99}Mo is to build a new multi-purpose research reactor facility.

We propose the establishment of a national facility for the replacement of the scientific, research and development, and isotope manufacturing capabilities of NRU. The Canadian Neutron Centre (CNC) is centred around a world-class high-neutron flux, 100-200 MW nuclear reactor. A network of laboratories and offices and secure checkpoints share the same campus. Accommodation for visiting researchers should be closely integrated with the facility.

CNC mission

- Support the development and implementation of government policies and initiatives in identified strategic areas, such as energy, environment, health, and communications.
- Operate as a national nuclear science and technology facility, for the benefit of Canadian and international academia and industry.
- Increase the competitiveness of Canadian industry through the application of neutron beam research and nuclear science and technology.
- Innovate and manufacture radio-pharmaceuticals which will improve the health of Canadians.
- Be a safe and secure steward of Canada's environment and nuclear materials.

Just some of the central missions that the CNC reactor addresses for medical isotopes, materials research, and the nuclear industry are outlined in the diagram on Page 10.

CNC core facilities

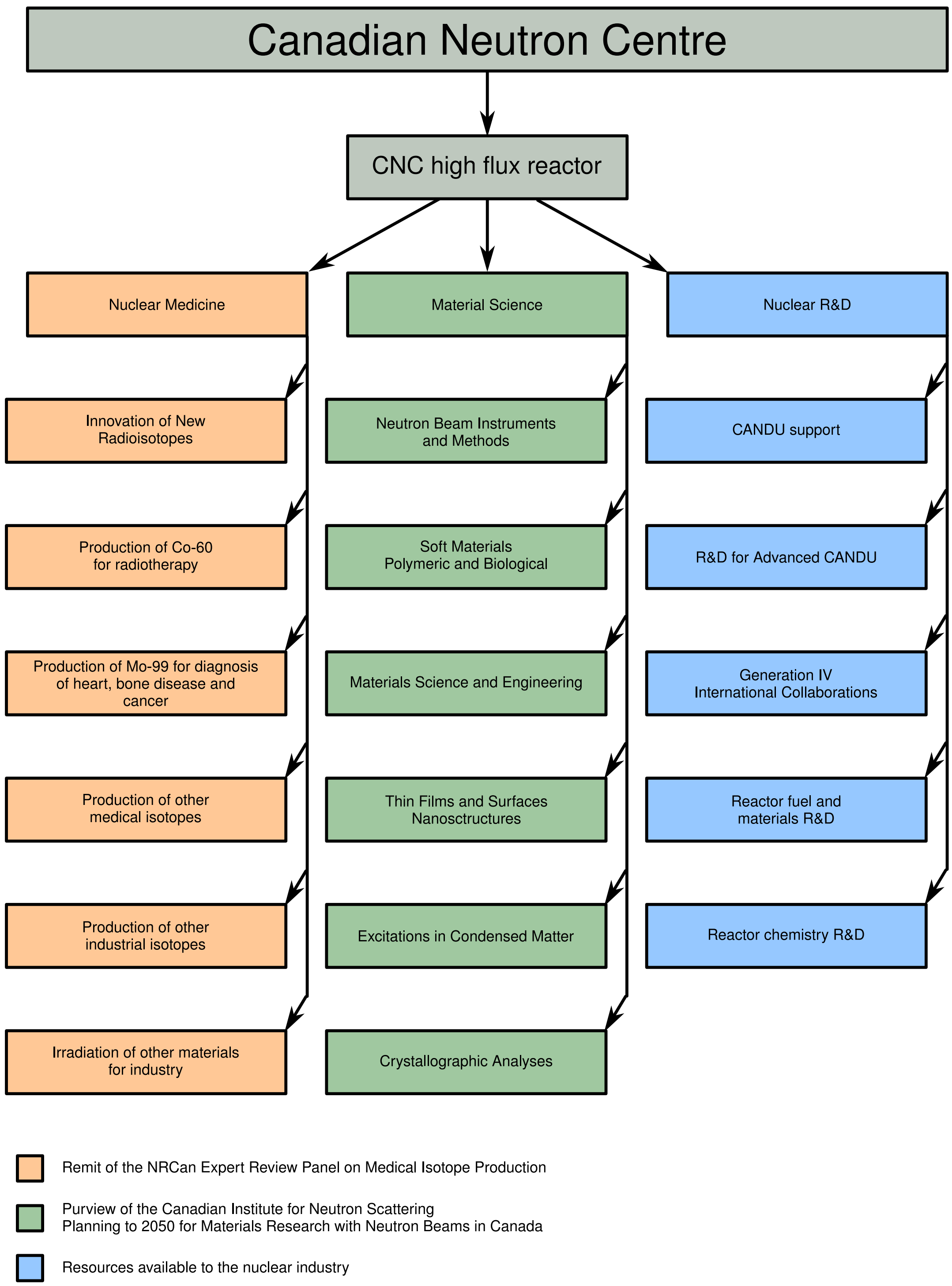
- The CNC high flux, low-enriched uranium (LEU) reactor, with a minimum of 10×10^{14} neutrons/cm^2/s in-core flux.
- Hot-cells for fuel and irradiated product handling.
- Medical isotope processing laboratories.
- Both hot and cold neutron sources, feeding neutrons in to Reactor and Guide Halls
- Attached laboratories (chemical and biological) and workshops (electronics, fabrication, machine).
- Offices and meeting rooms, accommodation for visiting scientists

CNC managment

- The mission of the CNC should be entrusted to an arms-length Board of Trustees, comprised of the stakeholders; Canadian universities, industry, Federal and Provincial governments.
- To ensure that individual strategic initiatives are being carried out, individual sub-committees representing the scientific, industrial, and medical isotope missions of the CNC report annually to the Trustees.
- Annual reports filed on behalf of the Trustees to the Auditor General report on the fiscal stewardship of the CNC, as well as scientific progress.

CNC location

The CNC should be located near the industrial partners it will support, the researchers who wish to use


Canadian Neutron Centre
CNC high flux reactor
Nuclear Medicine
Material Science
Nuclear R&D
Innovation of New Radioisotopes
Production of Co-60 for radiotherapy
Production of Mo-99 for diagnosis of heart, bone disease and cancer
Production of other medical isotopes
Production of other industrial isotopes
Irradiation of other materials for industry
Neutron Beam Instruments and Methods
Soft Materials Polymeric and Biological
Materials Science and Engineering
Thin Films and Surfaces Nanosctructures
Excitations in Condensed Matter
Crystallographic Analyses
CANDU support
R&D for Advanced CANDU
Generation IV International Collaborations
Reactor fuel and materials R&D
Reactor chemistry R&D
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Purview of the Canadian Institute for Neutron Scattering Planning to 2050 for Materials Research with Neutron Beams in Canada
Resources available to the nuclear industry

it, and if possible, existing infrastructure for radioactive materials handling and waste disposal. This would make the Chalk River site in Ontario the ideal location. This site currently has functional nuclear operation infrastructure, including a licensed site, security, access management, waste handling and management, and isotope processing facilities. It would be a sound financial choice to exploit existing infrastructure where possible, rather than reproducing all of these expensive facilities in another part the country. Chalk River is also reasonably close to most of the major research universities and NRC institutes in Ontario and Quebec, and the proximity of the international airport in Ottawa means that researchers from across Canada and around the world have convenient access to the facility.

Chalk River Laboratories is currently the private property of the crown corporation Atomic Energy of Canada, Ltd. (AECL). Regardless of the long-term future of the AECL as an ongoing concern, the CNC should be an independent entity, in terms of both operation and physical access. The CNC would be incorporated into, or attached to the current facilities, through contracts that recognize its operational and management independence. While a commercial entity such as AECL could not *own* the CNC (this would be inconsistent with the CNC's mission as a key component of Canada's infrastructure for science and industry and might interfere with its operation as an open-access user facility) it is probable that such an organisation might be contracted to *operate* the reactor facility, given their long history and experience base.

CNC size and scope

The proposed CNC has a broader scope of activities than that of NRU currently, and represents a return to the original mission of the facility when Chalk River Laboratories was primarily a centre of scientific research. To place the CNC into perspective, we compare the CNC to two facilities located in countries with per capita GDPs similar to Canada's.

Two benchmarks of this type of facility are the Australian Nuclear Science and Technology Organization (ANSTO) in New South Wales, Australia and the Intitut Laue-Langevin (ILL) in Grenoble, France. Both are publicly funded, major centres of scientific excellence. We can gain an estimate of the size of the CNC through their published data.

The ILL is an collaboratively funded effort of three Associate Countries France, Great Britain, and Germany (72% of operating funds), and additional support from nine additional scientific members (17% of operating funds). The ILL is primarily concerned with neutron beam research, and has a staff of 480 (19% scientists and thesis students) and total income of 82.4 million Euro, where the facilities and reactor operational costs are about half this amount. Since neither isotopes or nuclear industry services play a significant role at the ILL, income through commercial channels account for just 3.4% of revenue. [1]

In our report "Planning to 2050", we envisioned a neutron facility on par with the ILL in terms of size (see a drawing and conceptual schematic of the neutron beam facility on Pages 14 and 15). However, fundamental science research with neutrons dominates the activities of the ILL, with essentially no significant commercial activities. As a result, the ILL funding model requires significant multi-national contributions to achieve the scale of scientific success the ILL enjoys today. By contrast, the CINS vision of the CNC includes a substantial commercial component, including medical isotope production, support for the nuclear power industry and fee-for-service access to neutron beam instruments and irradiation sites. These form part of the integrated vision of the CNC as a major component of Canada's research infrastructure that supports both science *and* industry.

ANSTO, in New South Wales, Australia, employs over 1,000 people, around one third of whom are engaged in full-time research in a wide range of disciplines across their 70 hectare campus. With the new OPAL reactor, medical isotopes, neutron beams, and nuclear technology make up the bulk of the yearly R&D activity at ANSTO, although there are also excellent programs spun-off from these endeavours in environmental and accelerator research.

ANSTO enjoys robust fee-for-service and intellectual property programs; fully one quarter of ANSTO revenues derive from isotopes (10%), fee-for-service (5%), and other commercial grants and sales income (10%). This technology development focus of ANSTO certainly accounts for a significant percentage of their employment base. Note that the isotope business is expected to grow substantially to fill the needs left by NRU's closure as OPAL receives approval from Australia's regulatory bodies to ramp-up production. [2]

These are the successes that the CNC hopes to emulate, by creating an environment conducive to creative scientific enterprise, supportive management

[1] ILL Annual Report 2007-2008

[2] ANSTO Annual Report 2007-2008

that wants to expand opportunities for technological development, and a foundational support for basic science.

The CNC and other expressions of interest

If Canada is to position itself as a reliable, stable source of medical isotopes for the international market, a second domestic source of ^{99}Mo will definitely be needed. The two reactor sources would serve as back-ups for each other and permit longer down times by covering production short-falls. This second source could produce modest quantities while the CNC is operating, and ramp up to replace the CNC production while it is down for routine maintenance. Similarly, the CNC would perform the same back-up functions for the second source. With proper coordination in the scheduling, the two facilities could easily cover for each other to guarantee a continuous stable supply.

A possible location for the second facility is the University of Saskatchewan. There is a strong interest in adding to the value of the uranium that is mined extensively in Saskatchewan and a research reactor would make a perfect complement to the Canadian Light Source (CLS). The synergies between x-ray and neutron based research and engineering would bring substantial benefits to Saskatoon and could lead to the creation of a new technology cluster.

The Saskatchewan proposal envisages a high-flux reactor for neutron beam research and isotope production, without the in-core nuclear engineering component of the CNC, making it a high-end conventional research reactor concept. It will complement the capabilities of the CNC and with both facilities in operation, Canadians will be in the enviable position of having two new world-class neutron beam facilities dedicated to research in engineering and science. Two locations in Western and Eastern Canada will make it easier for a much wider community of neutron beam users to develop and expand, with coordination and cooperation between the two facilities allowing substantial overlap in high-demand activities (such as triple-axis work and powder diffraction) while enabling a degree of specialisation that takes advantage of local expertise or interests. It may even be possible to formally link the CLS, CNC and U. Saskatchewan reactor user access programs so as to coordinate the user communities and exploit the possible synergies to a greater degree.

Coordinating the construction of a second independent isotope source in Saskatchewan with the CNC project will lead to a more reliable, stable supply of medical isotopes and position Canada as a world leader in the medical isotope business. Significant cost savings and licensing simplifications could be achieved by locating all of the hot-cell and waste management functions on the Chalk River site, where such facilities already exist and are licensed. In this model, the Saskatchewan reactor carries out the target irradiations and then sends them to Chalk River for further processing. Multiple parallel hot cells already exist so the risks of supply interruptions as a result of a hot-cell problem, are minimal. Waste management would also handled at Chalk River. Material transfer from Saskatchewan to Chalk River could be effected quite rapidly by air. There is a good regional airport in Pembroke, about 30 minutes driving time from the Chalk River site, so the transfer could be completed by a small business jet in a few hours.

Conclusion

A single-purpose dedicated isotope production reactor is unlikely to be economically viable as its capital costs could not be recovered through sales-derived revenues, at least without a large adjustment of global price points. Thus such a proposal is unlikely to be financed strictly by the free-market, and requires a public-private partnership. The single-purpose solution amounts to a massive subsidy of an isotope supplier: the very business that the Government has clearly indicated that it wants to avoid.

By contrast, the CNC is a major piece of infrastructure for science and industry that will surpass the capabilities of NRU in all three of its current functions. With full engagement of all stakeholders during the design phase, a flexible management outlook and a mandate to operate for the benefit of those stakeholders, the CNC would empower Canadians to explore a much broader range of reactor-based activities.

- It would be a magnet for highly qualified engineers and scientists seeking a platform on which to express their creativity, and would enable new Canadian businesses to access a world-class facility at commercially meaningful rates and develop markets and products in a wide range of industries.

- Research and development at the CNC would support the development and stewardship of our nuclear power industry and ensure that

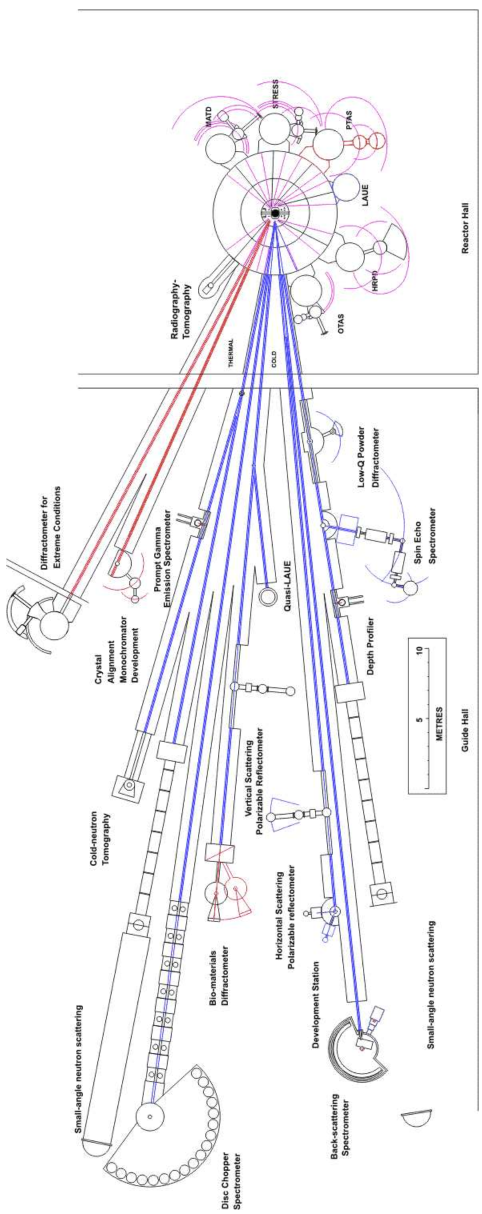
Canada can continue to play a meaningful role in the international Generation-IV reactor development project.

- A stable source of medical and industrial isotopes would attract commercial producers.

- Neutron beam research, already one of Canada's international strengths, would be energised, and the best scientists from around the world would be drawn to the facility; some would come to exploit the expertise available to support their research and would enrich the experience of the Canadians based at the CNC, others would choose to stay, building their scientific career around the world-class facilities at the CNC.

- A second, complementary source, located in Saskatchewan would provide for a more reliable supply, and the synergistic relationship between research carried out with neutron beams at the Saskatchewan reactor, and with x-ray beams at the nearby Canadian Light Source would open new opportunities for science and industry in Canada.

Artist's rendition of the CNC, with the isotope processing facility behind the reactor (blue building), and the neutron guide hall with its black roof in the foreground.



Schematic of possible CNC neutron beam instruments arrayed around the CNC reactor and neutron guide hall. These instruments have previously been identified by CINS scientists as the most relevant to research today and in the foreseeable future, while capitalising on Canadian expertise. For a detailed account of the capabilities of these instrument types, please see the CINS document “Planning to 2050”.

3

Technical feasibility

Several new research reactors have been successfully completed and commissioned around the world in recent years (e.g. FRM-II in Germany (2004) and OPAL in Australia (2006)) and Canada already has a substantial body of expertise in reactor construction as evidenced by AECL's commercial CANDU power reactor program. We also have many reactor-decades of experience operating research reactors in Canada, and similar levels of experience with the hot-cell and isotope extraction facilities that would be needed at a new multi-purpose research reactor in order to produce medical isotopes for use in North America.

A modern, safe, high-flux isotope reactor is not experimental or untried technology. Comparable reactors are already in operation around the world, using designs that incorporate low-enriched uranium (LEU) fuel to adhere to current international treaties on non-proliferation. **There is very little risk that the CNC will not work as designed.**

The CNC would certainly be a major project that would put heavy demands on the expertise of many highly qualified Canadian scientists and engineers, but it is precisely these kinds of projects that attract and inspire the best people, and the construction project alone would energise Canadian industry and prepare a large number of Canadian small to medium enterprises to take part in the coming clean energy revolution.

Hot-cell and waste management facilities already exist and are in use on the Chalk River site. While it is likely that these would need to be upgraded and expanded to handle a new 50-year production mandate, the basic infrastructure, expertise and licencing are already in place. This would not be a green-field site or a cold-start. Nor would it require the development of new or experimental technologies.

With a commitment to new facilities in place and construction under-way, there would be the time and motivation to undertake the move away from HEU targets to more proliferation-resistant LEU target technology. Processing of such targets is already under-way in the OPAL facility in Australia with Health Canada's approval[1], so the technology transfer should not present any significant challenges. Indeed, as we envisage NRU continuing to operate and produce medical isotopes throughout the construction and commissioning phases of both the CNC and Saskatchewan projects, there would be an opportunity to develop and test the LEU target processing technology using NRU-irradiated targets, before the new facilities came on line. This demonstrates the feasibility of LEU technology in Canada well ahead of it being needed at the new facilities.

[1]Lantheus Medical Imaging `http://www.lantheus.com/News-Press-2009-0709.html`

4

Timeliness of Proposal

As noted earlier, it is critical that the Government move on this project as soon as possible. With other countries building or expanding their nuclear and neutron-beam research facilities, a failure to match this effort in Canada will lead to a rapid and irreversible migration of talent and expertise out of the country.

In addition, if Canadian based companies are to remain in the commercial isotope business, the uncertainty around the isotope supply must be settled definitively. Already, other countries and organizations are considering their options and developing their own solutions. [1]

High entrance cost, lack of local experience, and issues with technical feasibility will slow some of the entrants down, but prompt action from the Canadian Government could easily undercut most of the fledgling proposals being developed by re-establishing Canada as a major player. We have the track record and history already in place.

All that is needed is a new source – a new reactor.

The economics of a stand-alone isotope reactor are not attractive [2], and a large reactor facility is needed to produce an economically viable output, thus many potential competitors will find it difficult to obtain the large-scale financing needed. There is still time for Canada to stake a claim in this important market.

A new multi-purpose research reactor facility will support far more than just medical isotope businesses. It will also provide opportunities for the in-core research needed both for responsible stewardship of the international CANDU power reactor fleet and also for Canadian participation in the international Generation-IV reactor development project. The CNC will also support fundamental and applied materials research using neutron beams that will contribute both to our industrial competitiveness and our international research standing.

Timing is critical. Public awareness of the key role that nuclear medicine plays in Canadian healthcare has never been stronger. Market opportunities exist *now* because there is a clear shortage in the supply chain and many players are seeking to capitalise on the situation. The existing expertise on the Chalk River site could easily be lost if a commitment to a new facility is not made soon. Moving to a new production facility provides an opportunity for an orderly move from HEU to LEU targets for ^{99}Mo production, with development work at NRU guiding the final design requirements of the new facility. The Province of Saskatchewan has expressed unprecedented interest in supporting a reactor facility on the University of Saskatchewan campus, and if this project is properly coordinated with the CNC project at Chalk River, we have the chance to put Canada back into a strong leadership role, not only in medical isotope supply and development, but also in nuclear engineering and materials science using neutron beams.

[1] "Canada's medical isotope industry in peril as U.S. moves to make its own supply." Globe and Mail, July 13, 2009.

[2] "Capturing the full potential of the uranium value chain in Saskatchewan", Uranium Development Partnership, March 31, 2009. `http://www.saskuranium.ca`

5

Expectations of Government

There is an important social contract between science and society; that excellence in scientific research is tied to the economic, cultural, and physical well-being of the nation. Nowhere is the history of this contract more evident than in the history of the NRU reactor and the medical isotopes made there. NRU is arguably one of the most important and rewarding investments ever made by the Canadian Government.

The Canadian Neutron Centre is a major piece of infrastructure that will support and enhance science and industry in Canada. It is by definition, "large scale science", beyond the means of one, or even a consortium of universities. As such, it is appropriate that the Government of Canada finance its construction, likely with assistance from Provincial partners. This phase of the project will generate thousands of new direct jobs in many different areas including design, construction, manufacturing, and administration.

It is important to point out that the CNC is not to be considered a commercial enterprise, competing against free-market forces and covering its operating budget and capital amortisation costs through revenue-generating activities. It will be, first and foremost, a major component of Canada's infrastructure for science and industry, an investment in Canada's future through fundamental and applied research. Medical isotopes, industrial services with neutron beams, irradiation services, technology transfer, intellectual property development, etc., will be key activities at the CNC. They will be provided with an eye to cost recovery, as part of a responsible fiscal policy for the investment of taxpayer dollars, but they cannot be expected to cover the full cost of the facility.

On-going operational funding of the CNC must therefore find a place in the base budget of one or more relevant Federal agencies. As a major component of Canada's infrastructure for science and industry, the primary functions of the CNC likely fall under purview of the Department of Industry. This Government Department may seek to involve the National Research Council as an agency with a strong track record in research reactors (they were leaders in the ZEEP, NRX and NRU projects at Chalk River), a decade of experience in operating a neutron beam research laboratory (the Canadian Neutron Beam Centre, at Chalk River), and a mandate to provide research connections between academia and industry: a central function of the new CNC. Finally, Canadian universities will likely contribute to individual projects and programs, through faculty hiring, and grant support from sources such as NSERC, or the Canadian Foundation for Innovation (CFI).

Construction of the CNC is also a economic stimulus. The expertise developed during the construction phase will greatly enhance the capabilities of many Canadian small-to-medium sized enterprises's and so enhance their competitive position when bidding on international projects in the growing nuclear power industry. As most of the expertise and materials that will be used in the construction of the CNC will be Canadian-sourced, essentially all of the capital costs will be spent in Canada and this spending will act as a broad-based stimulus in the construction and engineering sectors of the Canadian economy.

The CNC will be a flexible multi-purpose platform that will enable a great variety of research, development and production projects. With access to a new state-of-the-art facility, Canadian enterprises will be able to open new markets, develop new products, obtain key data that will enhance production and competitiveness. Canadian researchers will be able to train new generations of highly qualified people who will exploit the unique capabilities of neutron beam techniques in both fundamental and applied research, enhancing Canada's international reputation. Most of these benefits, while accruing directly to "Canada" are too long term or diffuse to be supported directly by private industry, and must therefore be undertake by the centre of Government.

One final, but key requirement of the Government involvement, is the need to establish a proper governance structure. As the primary funding source, the Government will be able to construct a management structure that ensures that the CNC is operated as a multi-purpose facility for the benefit of all users. Everyone who needs access must be able to gain timely and effective access to the facility at appropriate costs; fundamental research would gain access through a peer-reviewed proposal process and be supported by the operating grants of the facility, as is the case at all international neutron beam facilities. Development work leading to non-proprietary publication of results might expect to receive partial support, while proprietary research and strictly commercial activities should pay full, realistic costs. We suggest a Board of Trustees be established, with representation from all user communities, that can ensure the missions of the CNC are being met, while answerable to the Government and the Auditor General. This Board's decisions will be guided by recommendations of sub-committees representing the three primary functions of the CNC, as well as any future direction of the facility.

6

Regulatory Issues

The most appropriate location for the CNC would appear to be the Chalk River site currently housing NRU. This site is already licensed for nuclear industrial activity, and all of the nuclear and security infrastructure is in place. Licensing a new reactor on this site would appear to present the fewest obstacles.

The neighbouring population has lived with nuclear reactors ever since nuclear reactors have existed (ZEEP was the first reactor built outside the US). They have direct experience of the economic benefits of a research facility and understand the safety and environmental issues.

The Chalk River site already has operating hot-cells and experience with the handling of the irradiated ^{235}U targets used in ^{99}Mo production. While we would anticipate any new facility would have its own hot-cell facility, the existing ones could be retained while the new ones are being commissioned, serving either as a back-up in case of problems or as a project accelerator so that production could be started as soon as the new reactor was ready, without having to wait for the commissioning of the new hot-cell facility.

Finally, the Chalk River site already has a well functioning waste management capacity in place that handles the waste stream from the existing ^{99}Mo production activity. This will likely require expansion to accommodate a new 50-year production cycle, especially if there is a move to lower enrichment targets, but clearly the basic infrastructure is in place, and licensing and expansion should not present major challenges.

One objective of the United States' National Nuclear Security Administration's Global Threat Reduction Initiative is to minimize the risk of nuclear proliferation by phasing out the non-military use of highly enriched uranium (HEU). Currently the only global supplier of low-enriched uranium (LEU) derived ^{99}Mo is ANSTO in Australia. This ^{99}Mo has already been approved for use in the North American markets[1]. Thus there should not be any regulatory hurdle to approval of the CNC using LEU.

By using the second facility in Saskatchewan purely for the target irradiation step of the ^{99}Mo production cycle, and locating all of the hot-cell and waste management activities on the already licensed and established Chalk River site, the environmental impacts of the Saskatchewan facility can be greatly reduced. This will simplify the siting and licensing requirements and should reduce the complexity of the regulatory evaluation, address reservations of the surrounding population and speed up the approval process. Transfer of the irradiated targets from Saskatchewan to Chalk River could be accomplished in a few hours by air. There is a suitable regional airport in Pembroke (about half an hour's drive from the Chalk River facility) that could accommodate the required aircraft. Flying into Pembroke rather than Ottawa greatly reduces the driving distance and avoids the non-trivial issue of traffic on the 417 highway through Ottawa. Total transfer times of the loaded flask from Saskatoon to Chalk River should be in the 5-6 hour range depending on the type of aircraft used.

[1] Lantheus Medical Imaging `http://www.lantheus.com/News-Press-2009-0709.html`

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Risks and mitigation strategies

The two major risks associated with the CNC-based production of medical isotopes would appear to be (1) start-up delays, and (2) supply interruptions once the CNC is operating.

1. Start-up delays.

   There are two possible origins of start-up delays, with quite different impacts.

   (a) Delays in committing to the project could cause serious and lasting damage in many areas. With NRU clearly coming to the end of its operational life, everyone who works at or depends on NRU will be assessing their employment options. Industrial users will look elsewhere to set up operations, researchers will seek connections with more modern laboratories, and technically competent personnel will look for new employers. The site will be steadily drained of knowledge and expertise.

       A firm commitment to a new facility will retain the existing staff and draw in a new generation. It will energise the facility and provide a new focus for activities. People and industries will start to think of new opportunities and projects.

       It is essential that we create a new future as soon as possible before an old past drains the human capital out of this important component of Canada's research infrastructure.

   (b) Delays in completion of the project would also have serious negative impacts on the utilisation of the facility. It is essential that these be avoided as they can sap the energy out of a project. The keys to avoiding such delays are proper planning and proper funding.

       The first stage of the project (as noted below) is to establish a properly specified and fully costed design that will meet all of the user requirements. This is a serious undertaking and must be completed in a diligent manner.

       The second, and no less important stage, is to secure the required level of funding as a well-defined firm commitment. This commitment must also include a realistic mechanism for providing the proper level of operating funding for at least the first 5–10 years of facility operation, otherwise we risk crippling the facility before it is even finished.

       Realistic construction funding should be secured on the basis of a diligently prepared design costing. It is essential that proper trust be established in this process so that the Government can be certain that the project will come in on the budget requested, and the team managing the construction project can know that the monies needed to do the job properly are firmly committed and available.

       Changes of heart leading to funding cuts must be avoided, just as dishonest costing cannot be tolerated, which would leave the government under pressure to pay for the cost overruns.

2. Supply interruptions would also place the project at risk.

   Every nuclear reactor needs down time for maintenance, fault correction, upgrades, fuel changes, etc. One special feature of NRU was it capacity to be re-fuelled while operating at power, reducing some of the down time issues.

If the reactor is off, no isotopes can be produced and a shortage ensues. Prior to the leak-induced shutdown of NRU, the shortages were managed through a combination of coordination with other suppliers and very short shutdown times. The former is essential, but the latter approach is not desirable and ultimately leads to a serious backlog of deferred maintenance issues.

The operating schedule of the CNC is likely to include fewer, but much longer shutdown periods than NRU so as to permit more orderly and complete maintenance. This will demand better coordination with other supply sources and greater redundancy in the supply chain. It is possible that by the time the CNC goes into production and NRU is finally retired, some new production facilities will have been added around the world. The global awareness of the critical need for medical isotopes coupled with the fragile nature of a supply chain that relies on 40–50 year old reactors, will certainly lead to new sources being developed. However, it is also likely that the ageing global population will lead to increases in demand for the heart and cancer tests that ^{99}Mo is used for. A recommended method for a secure and stable Canadian supply of ^{99}Mo would be a separate, coordinated reactor source, such as that proposed for the University of Saskatchewan, discussed above.

8

Benefits to Canadians

Benefits to health

It is clear from the recent reactions in the press, in Parliament and from the medical community, that the key role played by Canada in nuclear medicine for health care has been widely recognised. Our current dependence on an ageing domestic facility should not be exchanged for a new dependence on ageing foreign facilities. Our position as a major supplier of medical isotopes should not be abandoned, as to do this would involve abandoning not only our own citizens, but also many millions of people around the world who depend each year on Canadian-made medical isotopes for tests and treatments. Walking away from our current role would not make it easier to secure supplies in the future as we would have nothing to bargain with.

- Canadians need access to medical isotopes and this is not going to change.
- The world needs access to medical isotopes, so the market will continue to exist.
- A new multi-purpose research reactor could produce medical isotopes on a commercial basis and the revenues from this production could cover much of the operating cost of the reactor.
- A new multi-purpose research reactor could be used by industry to develop new isotope products and create new markets.

A new multi-purpose research reactor is needed to support our nuclear power industry, engineering research and both applied and fundamental scientific research, areas that Canadians have pioneered for decades.

Benefits to the nuclear industry

The domestic nuclear industry will be here for many years to come and will require flexible research facilities to test new components and fuels.

- Responsible management of the CANDU fleet will ensure their safe operation for years to come.
- New reactor designs require much more research to meet the technology goals of the Generation IV International Forum.
- As the nuclear power industry grows, Canada can more easily meet its targets of cutting greenhouse gas emissions.

Benefits to the broader commercial industry

A new multi-purpose research reactor will be used by Canada's broader commercial industry in many ways to improve products and develop new ones.

- Non-destructive testing with neutrons to evaluate forming, forging, welding and stress-relief techniques leading to better engineered and more competitive products.
- New neutron radiography techniques that would complement existing x-ray based methods and provide new ways to examine complete assemblies.
- Isotope production and product irradiation has found uses in the food and agriculture sectors, as well as the semi-conductor industry, just to name a few.
- New connections between CNC researchers and industrial users will stimulate the transfer of new technology to the private sector.

Benefits to science

- New neutron beam techniques will push the limits of knowledge of fundamental Physics such as the Standard Model.[1]
- Neutron beams will greatly improve our understanding of materials biological, chemical, and natural with thousands of individual experiments.
- Neutron-based experiments right now lead the way in many key research areas, such as:
  - High-Tc superconductors.
  - Hydrogen storage materials
  - Functionalized polymer surfaces.
  - High-strength alloys and composites.
- Over its 50 year life span, thousands of students will receive world-class scientific training.
- The CNC will attract highly qualified and talented individuals to move their research programs to Canada.

In-core and neutron beam based research at NRU has brought extensive benefits to Canadians over the past fifty years, a new facility will build on this legacy, harness the expertise that we have accumulated over half a century of innovation and leadership, and provide for the technological future of the next generations of Canadian scientists and engineers.

[1] http://nuclear.uwinnipeg.ca/ucn/

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How should we proceed?

The Canadian Institute for Neutron Scattering and the scientists it represents, has already produced a statement of the user requirements for a new multi-purpose Canadian Neutron Centre, as a world-class laboratory for materials research with neutron beams.

To make this project a reality, the next step is to establish a formal engineering design, in collaboration with all of the stakeholders, and develop an accurate costing estimate for the project so that the construction can be undertaken in a transparent and responsible manner.

A suitable Federal Agency should be identified that can lead such a project. It should be given both the mandate and the appropriate funding to coordinate a multi-departmental working group and bring forward a properly costed design proposal within the 2010 calendar year. Canada will then be properly prepared to consider an investment in a future Canadian Neutron Centre as a world-class resource for science and industry for the next 50 years.

Glossary

AECL – Atomic Energy of Canada, Ltd.
CANDU – "CANada Deuterium Uranium" nuclear power reactor
CFI – Canadian Foundation for Innovation
CINS – Canadian Institute for Neutron Scattering
CNBC – Canadian Neutron Beam Centre
CNC – Canadian Neutron Centre
CLS – Canadian Light Source
CRC – Canada Research Chairs Program
HEU – Highly enriched uranium
LEU – Low-enriched uranium
NRC – National Research Council Canada
NRU – National Research Universal reactor
NSERC – National Sciences and Engineering Research Council of Canada
MRS – NSERC Major Resource Support grant program
SME – Small to medium sized enterprises
TRIUMF – Canada's National Laboratory for Particle and Nuclear Physics

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