

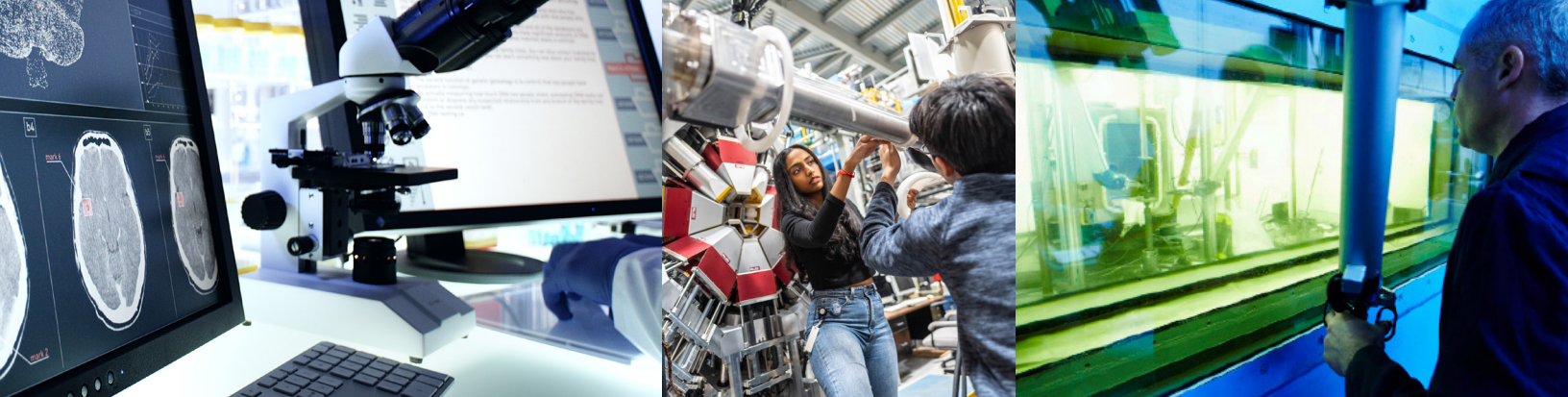


ORGANIZATION OF
CANADIAN NUCLEAR
INDUSTRIES

Clean Energy for a Low Carbon Economy



CANADIAN
NUCLEAR ISOTOPE
COUNCIL



Canadian Medical Isotope Ecosystem Directory

THE ISOTOPE PRODUCTION PIPELINE, ITS SUPPLIERS AND
ASSOCIATED INDUSTRIES

April 2023





The Canadian Nuclear Isotope Council (CNIC) is an independent organization comprising representatives from various levels within the Canadian health sector, nuclear industry and research bodies, convened specifically to advocate for our country's role in the production of the world's isotope supply.

The CNIC serves as a voice in safeguarding the continued availability of isotopes, ensuring our public policies are risk-informed and science-based, and support the highest levels of public health and safety. Leveraging existing infrastructure and expertise will have a significant positive impact on human health across the globe, keeping hospitals clean and safe while expanding Canada's leadership role in the global community by supporting new and innovative treatment.



The Organization of Canadian Nuclear Industries (OCNI) is an association of more than 200 leading suppliers to the nuclear industry in Canada and the international marketplace. OCNI member companies employ more than 15,000 highly skilled and specialized people in Canada who manufacture major equipment and components and provide engineering services and support for nuclear power plants in Canada and around the world. OCNI companies also work on medical and other safe applications of nuclear technology. OCNI also encourages and supports member companies in taking their unique capabilities and high standards of quality and customer value to offshore nuclear markets through partnerships with local suppliers, power plant designers, nuclear utilities and government agencies.

Directory prepared for OCNI and CNIC by Neil Alexander (Bucephalus Consulting), Milt Caplan (MZConsulting), and Marc Brouillette (Strategic Policy Economics).



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An ecosystem that delivers essential support to health care around the world and an environment in which any business producing or using medical isotopes will prosper.

Overview

Medical isotopes are an essential part of modern health care where they are used to diagnose and treat disease, sterilize key medical equipment and enable research. Modern medicine is heavily dependent on their availability using them in 40 million treatments a year around the world.

The manufacture, dispensing and use of medical isotopes is differentiated from other medical products because they are radioactive and:

- require specialized equipment and procedures to ensure they are handled safely
- are often short-lived with some useful for only a few hours before radioactive decay renders them ineffective
- use specialized and often scarce infrastructure, such as nuclear reactors or high-power accelerators, for their production, and can have restricted linear supply chains

Canada has played a key leadership role in establishing the value of medical isotopes and has cemented itself as a global leader in their production and supply. Key infrastructure has been harnessed and developed and an ongoing investment in people and skills has led to Canada developing one of the most sophisticated and supportive medical isotope production ecosystems in the world.

Many of these medical isotopes are used in manufacturing proprietary radiopharmaceuticals or other proprietary medical devices making this Canadian ecosystem an essential part of the supply chain for many international pharmaceutical companies. Canada has a burgeoning radiopharmaceutical research program and a rapidly developing radiopharmaceutical industry that is also supported by this ecosystem.

This directory contains descriptions of the companies that are members of the Canadian Nuclear Isotope Council (CNIC) and/or the Organization of Canadian Nuclear Industries (OCNI). It includes organizations that are directly in the production pipeline, the specialist companies in their supply chain, Original Equipment Manufacturers

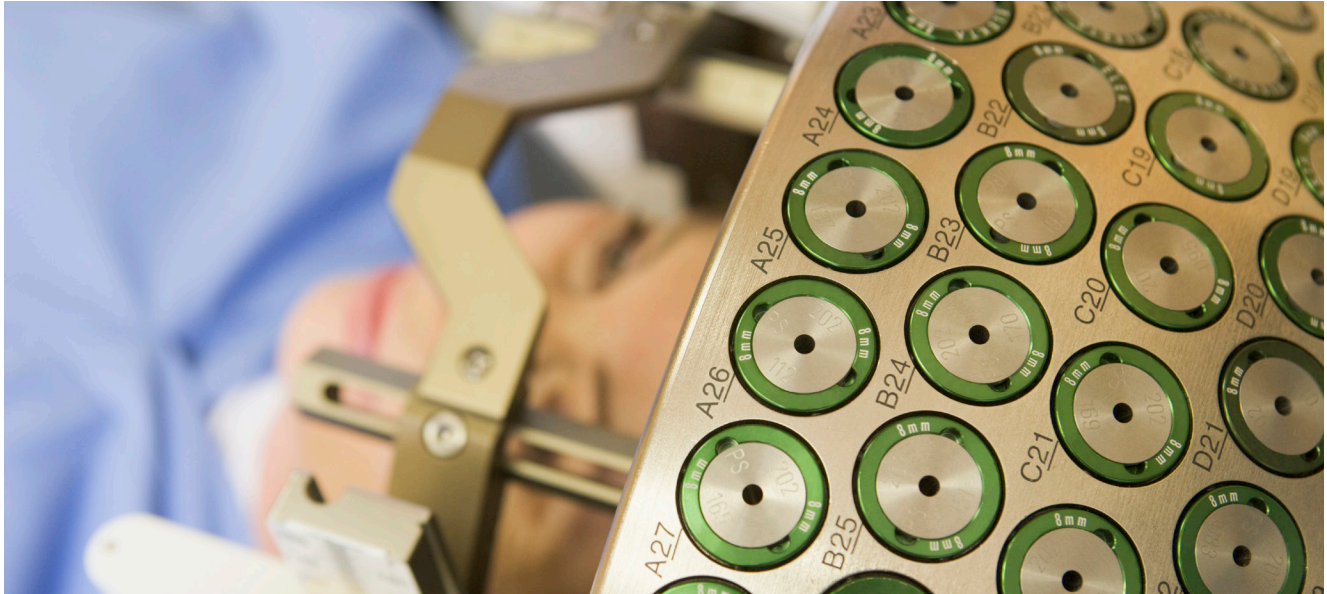
(OEMs) that supply the equipment that is used to irradiate targets and produce the source radioactive materials and companies that developed in Canada because they had access to those radioactive materials and use them in their products.

This comprehensive and cohesive production pipeline includes:

- a powerful and flexible research reactor at McMaster University
- a fleet of power reactors used for medical isotope production operated by Bruce Power and Ontario Power Generation
- many high-power accelerators including a 500 MeV machine operated by TRIUMF and a linear accelerator operated by Canadian Isotope Innovations
- production cyclotrons and linear accelerators operated by commercial organizations
- many companies selling bulk and/or dispensed medical isotopes
- supporting facilities including hot cells and glove boxes approved for cGMP production

These facilities are the backbone of this ecosystem and enable the production of a comprehensive range of isotopes and the flexibility to produce others that may be needed in the future. In this directory these capabilities are segregated in order to identify companies that supply the medical isotopes, those that will provide contact manufacturing services for third parties and those that will irradiate targets.

Additionally, the Canadian ecosystem includes a network of producers, typically operators of cyclotrons and associated processing facilities, which directly supply to their local hospitals and



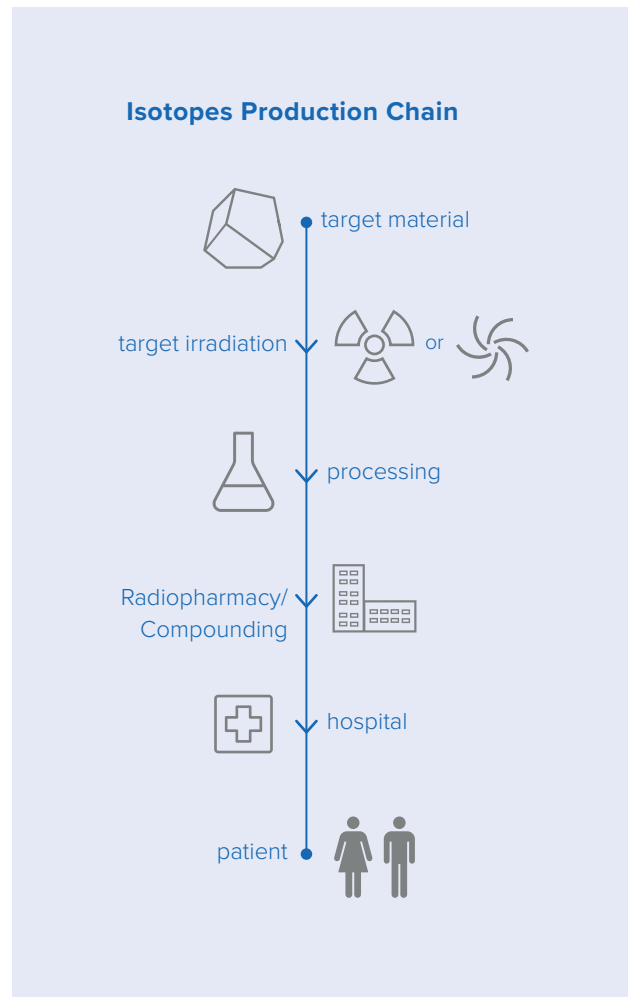
research institutes but do not make their products available on a commercial basis.

This production pipeline and its associated OEMs are supported by a supply chain of more than 30 companies that provide goods and services, both to Canadian producers and the international community that includes suppliers of:

- target materials
- shielding
- research and development
- regulatory support
- specialist engineering design
- specialist packaging and logistics
- remote handling and automated production processes
- translation and commercialization support

The demand for equipment to irradiate the targets has led to specialist OEMs such as Advanced Cyclotron Systems and Mevex developing and becoming part of the ecosystem, while the availability of the medical isotopes has led to the establishment of further OEMs such as Nordion, the world-leading supplier of sterilizers, and Best Theratronics with its range of External Beam Radiotherapy Machines, which use them in their products.

With a critical mass of capability, a storied history and access to essential infrastructure, this Canadian ecosystem is at the forefront of medical isotope technology. It continues to innovate to meet





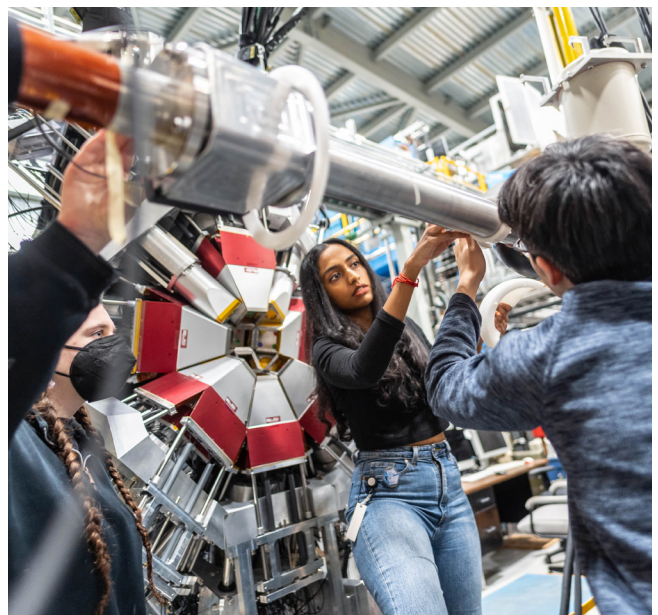
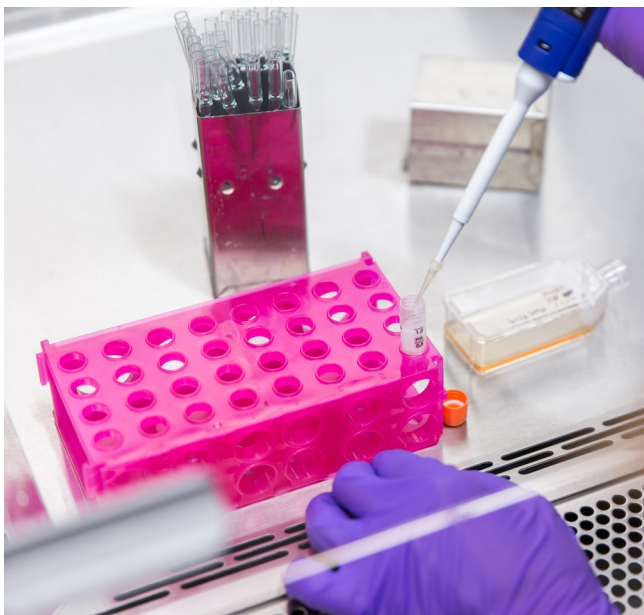
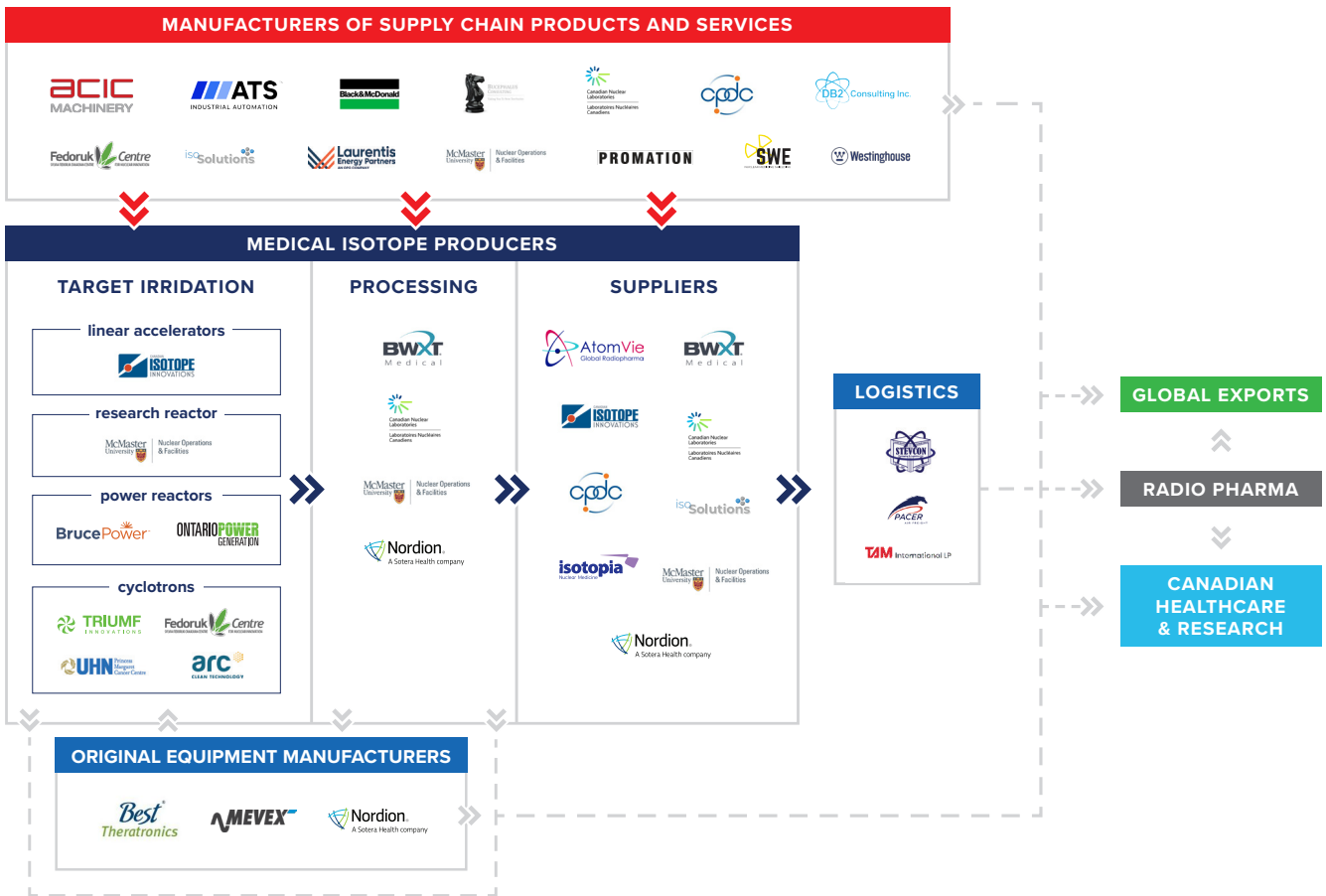
future needs created by the increasing demand for existing medical isotopes and the developing demand for new ones. Investments in new production routes that increase production capacity and expand availability are ongoing and include:

- Multiple routes for Lutetium-177 production, including new irradiation and new processing capacity, that will enable demand for an exciting new range of therapies to be met.
- Target delivery systems for the irradiation of targets in power reactors while they are operating, simultaneously increasing the world's medical isotope production capacity and improving the security of supply by diversifying the sources of production.
- Processes for the production of alpha emitters such as Actinium-225 to support trials of new Targeted Alpha Therapies (TATs) and then to meet commercial demand when it arises.
- New approaches to the production of Gallium-68 generators that will resolve an existing supply challenge.
- The novel use of linear accelerators to extend the range of medical isotopes including creating the capability to produce Copper-67.

- Novel methods for the production of Technetium-99m, the most commonly used medical isotope, to include commercial reactor, cyclotron and LINAC based approaches for both direct and generator-based production.
- Increased capacity to develop, translate and cGMP manufacture both diagnostic and therapeutic radiopharmaceuticals and support clinical trials of new medical isotope based products.

This directory describes the individual capabilities of the companies in the Canadian medical isotope ecosystem and profiles a vibrant and growing integrated industry. It is the description of an ecosystem that delivers essential support to health care around the world, and an environment in which any business producing or using medical isotopes will prosper.

Medical Isotopes in Canada



1

Isotopes a brief History

The first use of a medical isotope was reported in 1901, only five years after the discovery of radioactivity. Using the naturally occurring radioisotope radium-226, physicians successfully cured a tuberculosis patient of previously untreatable skin lesions. This discovery that the gamma rays emitted by radium-226 can induce localized tissue ablation elicited immediate interest from the medical community as a potential means of treating cancer.

Over the next 15 years, scientists and physicians designed sealed sources of radium-226 that could be used to treat throat, cervical, prostate, and breast cancers, to name a few.

The invention of the cyclotron – a small, circular particle accelerator – in 1931 marked a turning point for radioisotope scientists and medical practitioners alike. For the first time, radioisotopes of common chemical elements like phosphorus, iron, and iodine could be produced on-demand. Researchers quickly discovered that they could use the unique atomic signatures emanating from radioisotopes to create individual “timescapes” for each chemical element, as they traced the movement of radioisotopes – and by extension, their non-radioactive analogues – through both time and space. These new “radiotracer” studies of the absorption, biodistribution, and metabolism of common nutrients and minerals served as a foundation for the emerging science of biochemistry.

Until the advent of chemotherapy in the 1940s, radioisotope-based therapies remained the only effective means of combatting cancer other than surgery. For this reason, radium-226 based brachytherapy remained a standard treatment for numerous types of cancers through the 1950s, when it was displaced by more readily available radioisotopes generated in nuclear reactors and particle accelerators.

The Development of “Cobalt Therapy”

In the late 1940s, scientists began to consider a new radioisotope-based method of treating cancer. Rather than implanting a sealed source at the disease site, physicists could focus a beam of high energy radiation at the tumour from a distance of up to a meter, enabling them to treat cancers deep within the body. Due to its simple production logistics, long half-life, and high energy gamma rays, cobalt-60 was quickly identified as an appropriate radioisotope for this approach. Scientists put in a request to the recently established NRX research reactor at Chalk River, ON, and received the requisite cobalt-60 soon thereafter. Following months of collaborative development work between Canadian scientists and physicians,

the first patient was treated using the new External Beam Radiation Therapy (EBRT) approach at Victoria Hospital in London, ON, in October 1951.

Diagnostic Imaging

Advances in technology in the 1960s gave rise to a new branch of nuclear medicine: diagnostic imaging. Specially designed “gamma cameras” emerged that could record both still frame and dynamic images of the location of radioisotopes within the human body. Instruments suitable for visualizing radioisotopes with low energy gamma rays were classified as Single Photon Emission Computed Tomography (SPECT) scanners, while those designed to image positron emitting radioisotopes were designated Positron Emission Tomography (PET) scanners.

Chemists quickly developed methods of attaching radioisotopes to molecules with a wide variety of biochemical properties (Figure 9). By injecting one of these “radiopharmaceuticals” into a patient, physicians were now able to visualize processes such as myocardial blood flow, iodine biodistribution, and glucose metabolism at the molecular level. The images produced during these particular “diagnostic imaging scans” enable physicians to assess cardiovascular disease, thyroid function, and the spread of cancer, respectively. Today, the use of radioisotopes for diagnostic nuclear imaging vastly outstrips their use in brachytherapy, EBRT, and TIRT combined. An estimated 90 % of all nuclear medicine procedures are diagnostic rather than therapeutic, equating to well over 30 million imaging scans conducted globally every year.

During this time, Canada continued to play a role in the new field of diagnostic medical isotopes. By the 1970s, technetium-99m had emerged as the SPECT imaging radioisotope of choice due to its near-ideal nuclear properties, and easy production from the common nuclear fission by-product molybdenum-99. The National Research Universal (NRU) reactor (Chalk River, ON), soon established itself as a major global supplier of the 99Mo/99mTc medical isotope pair.



New Radioisotope Based Therapies

In the 1990s, changes in clinical management of diseases such as prostate cancer gave rise to demand for new medical isotope based therapies. Research in the 1980s demonstrated that brachytherapy using iodine-125 provides disease control of early stage prostate cancer, with minimal side effects compared to conventional therapies. As prostate cancer remains the most commonly diagnosed malignancy in North American men, the surging popularity of iodine-125 brachytherapy through the 1990s soon outstripped the global supply of this radioisotope. In response, Canadian researchers developed and commercialized a process for producing iodine-125 from the stable isotope xenon-124 using the nuclear research reactor at McMaster University (Hamilton, ON).

At the same time, Canadian researchers designed a new device for “radioembolic therapy” of liver cancer, a disease that typically has a poor prognosis. The active component of this therapeutic agent, which is now marketed around the world as TheraSphere, is the beta emitting radioisotope yttrium-90.

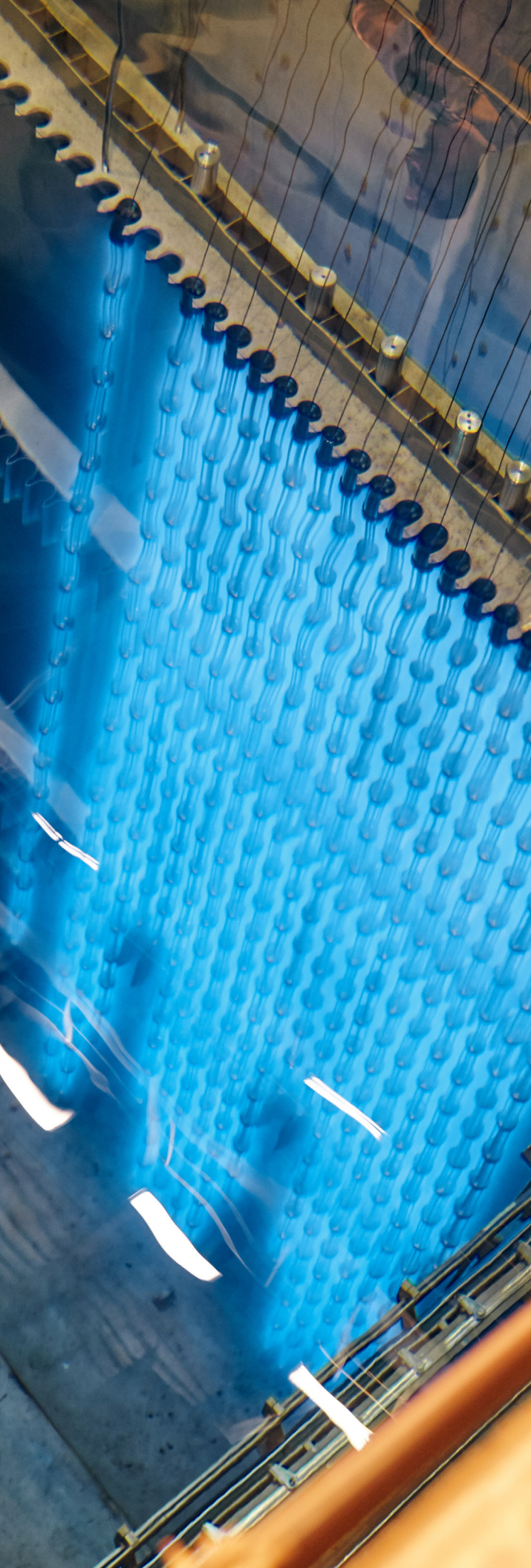
By the early 2000s, Canada was the one of the largest producers and exporters of medical isotopes in the world. Between the McMaster and Chalk River sites, Canada was supplying 60 % of the world’s iodine-125; Canada’s nuclear power reactors were exporting cobalt-60 to meet increasing demand for sterilization facilities; new cyclotrons were providing medical isotopes for domestic and international use; and the NRU reactor (Chalk River, ON) generated 40 % of the global supply of molybdenum-99, the precursor to the ubiquitous SPECT isotope technetium-99m, used in over 35 million diagnostic imaging procedures every year.

Canada’s Role Today

The year 2018 marked the end of an era for radioisotope production in Canada, as the NRU reactor was taken out of services after six decades of supplying medical isotopes to the world. Nevertheless, Canada continues to play an important role on the global stage as a large-scale producer and exporter of several key medical isotopes including cobalt-60, palladium-103, and iodine-125.

At home, new cyclotron facilities across the nation are increasing Canadians’ access to PET imaging, while active clinical and laboratory research programs are working with world-class GMP production facilities to bring new medical isotopes – and medical isotope based diagnostics and therapies – to patients in Canada and around the world.

The landscape of medical isotope production in Canada is diverse, due in part, to the long-standing and world-class research into reactor and accelerator research. Canada is a leader in reactor construction and application for the production of medical isotopes that have been used globally for the past several decades. Nearly the complete supply chain for the production, processing and delivery of medical isotopes is represented in Canada. In addition, we have a very well-equipped nuclear medicine infrastructure as this directory will detail.



2 Directory structure

This directory includes companies that are members of either the Canadian Nuclear Isotope Council or the Organization of Canadian Nuclear Industries and that are:

- involved in the production and sale of medical isotopes
- in the supply chain that supports the production of medical isotopes through the provision of goods and/or services
- associated industries that are located in Canada because of their easy access to the medical isotope produced here
- Original Equipment Manufacturers (OEMs) whose products play a key role in the production pipeline.

The directory is presented in four parts to reflect the various and significant components of the supply chain. The first is focused on the production pipeline - the companies directly involved in the production of the medical isotopes. This is followed by descriptions of companies that supply irradiation equipment used by those companies, and suppliers of equipment that are located in the ecosystem because long-lived medical isotopes are incorporated into the equipment they supply. The directory finishes with a listing of the supply chain companies that provide specialist goods and services that support the production pipeline.

The section on the production pipeline includes organizations that supply medical isotopes, those that undertake contract manufacturing for others and those that carry out the irradiations that support production. As many of these companies provide a range of different services, these organizations are described comprehensively in the final section on the production pipeline.

3

Production pipeline

3.1 Medical isotope suppliers

At the end of the medical isotope production pipeline there are the companies that sell the medical isotopes in a form suitable for either end use or for synthesis into radiopharmaceuticals and who typically will arrange the logistics using experienced delivery companies. Some of the organizations involved run a linear supply chain with full responsibility for acquisition of targets, irradiation of targets, processing, dispensing and distribution. At the other end of the scale others act as brokers acquiring medical isotopes from producers and providing a service to get them to the people that want them in the form that they need them. All these companies are included in the following list with the isotopes they supply, while the details of the companies are included at the end of the section.

In addition to the organizations listed here that trade nationally and internationally, Canada also has a network of 24 cyclotron production facilities producing very short-lived isotopes for the regional health care system and universities. Purchasers may investigate the potential for supply by contacting local universities or regional health authorities.

As well as selling isotopes themselves, many of the isotope suppliers also use their infrastructure to support the irradiation of targets and processing for others. These include:

- Bruce Power
- BWXT Medical Ltd.
- Canadian Isotope Innovations Corp.
- CPDC
- Isologic
- isoSolutions
- Isotopia Molecular Imaging Ltd.
- Jubilant Radiopharma
- Ontario Power Generation
- McMaster University Nuclear Operations and Facilities
- Nordion
- Sylvia Fedoruk Canadian Centre for Nuclear Innovation
- TRIUMF

3.2 Target irradiators

Canada has led the world in developing methods of irradiating targets using its infrastructure, which includes research and power reactors, cyclotrons and linear accelerators. Some organizations use their infrastructure to provide irradiation services to support production for third parties. These organizations are:

- ARC Clean Technology
- Bruce Power
- Canadian Isotope Innovations (linear accelerator)
- Isogen/Bruce Power (power reactor)
- McMaster University (research reactor and cyclotron)
- OPG (power reactor)
- TRIUMF/TRIUMF Innovations (high power and production cyclotrons)
- Sylvia Fedoruk Canadian Centre for Nuclear Innovation (cyclotron)

3.3 Processors of medical isotopes

Many organizations have processing capabilities but use them only to produce the medical isotopes that they sell. The organizations listed here also provide contract processing capabilities to third parties.

- AtomVie
- BWXT
- Canadian Nuclear Laboratories
- McMaster University
- Nordion

4

Production pipeline company descriptions

Company descriptions are in alphabetic order and include the companies listed in Sections 3.1, 3.2, and 3.3 above.



AtomVie Global Radiopharma Inc.

www.atomvie.com

Contact:

Ghadeer Shubassi, Associate Director, Business Development
ghadeer.shubassi@atomvie.com
289-683-0870

AtomVie Global Radiopharma Inc. (AtomVie) is a global leading Contract Development and Manufacturing Organization (CDMO) that recently launched as a spinout from the Centre for Probe Development and Commercialization (CPDC). AtomVie offers the full range of scientific, technical, regulatory, quality, logistics and business expertise combined with a specialized infrastructure for the development of your radiotherapeutics from Phase 1 to the commercial marketplace. AtomVie has in-depth expertise in radiolabeling with an array of radioisotopes such as Lu-177, Ac-225, I-131 and ligands that range from small molecules to peptides to small and large antibodies. In partnership with Isotopia, AtomVie produces Lu-177 (n.c.a.) from its own facility, offering a unique value proposition to its clients with Lu-177-based programs. Capabilities offered by AtomVie include:

- Analytical and process development
- Scale-up & stability studies
- Analytical and process validation
- Logistics to global destinations (North America, EU, Asia and more)
- Regulatory affairs (FDA, Health Canada and EMA)
- Routine clinical and commercial supply to meet the needs of our clients
- Supply of GMP-grade Lu-177 (n.c.a.)

We are building a state-of-the-art, multi-product facility that will be operational in 2024. AtomVie empowers the development of next generation radiotherapeutics.



ARC Clean Technology

www.arc-cleantech.com

Contact:

William P Labbe, Jr., President & CEO

blabbe@arc-cleantech.com

ARC is a clean energy technology company developing the ARC-100, an advanced small modular reactor (aSMR) offering inherently safe, reliable, and economical carbon-free power. Leveraging proven technology from the 30-year performance of its prototype, the ARC-100's simple, modular design provides 100 megawatts of electricity

and industrial heat that is cost-competitive with fossil fuels. Important applications include the decarbonization of heavy industry, the fueling of low-carbon hydrogen projects, and the creation of valuable medical isotopes.

As a sodium-cooled fast reactor, the ARC-100 will be capable of high-volume medical isotope production at highly efficient rates. Because the production of large quantities of radioisotopes with the highly specific activities required for many medical applications is dependent on the neutron energy used for target irradiation, the ARC-100 offers significant advantages. Twenty different medical isotopes have been identified as primary candidates for production.

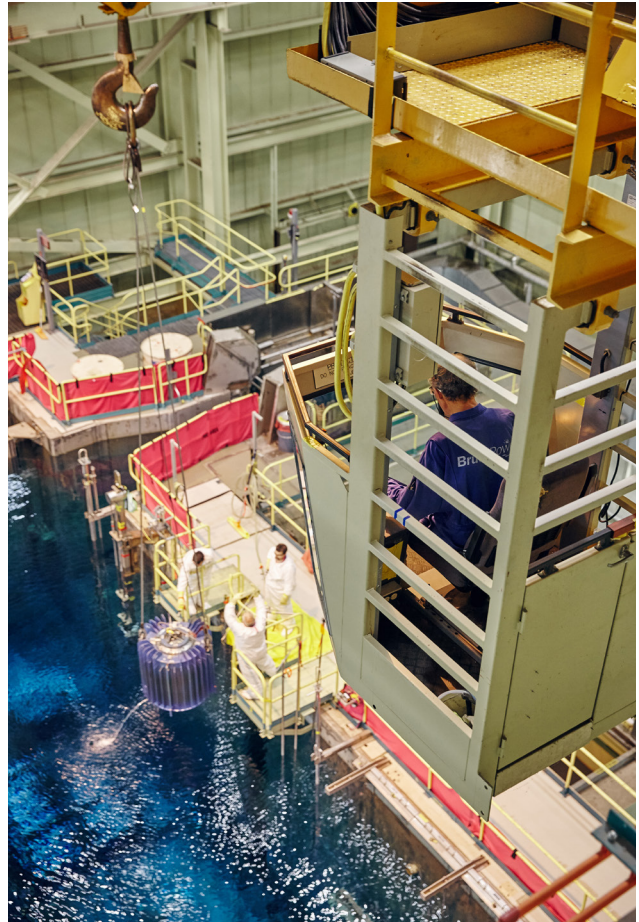


Bruce Power

www.brucepower.com

Bruce Power has used its fleet of reliable reactors for over 30 years to produce the radionuclide Cobalt-60. Bruce Power's supply of Cobalt-60 helps to sterilize 40 per cent of the world's single-use medical devices, including sutures, syringes, masks, gloves and more. Since 2019, Bruce Power has also been producing medical-grade Cobalt-60, which can be used to deliver focused treatment to cancers such as brain or breast.

More recently, Bruce Power has expanded the medical isotope line of business through a partnership with IsoGen, a privately held Canadian corporation owned by Framatome Canada Ltd. and Kinectrics Inc. The partnership is focused on the installation and commissioning of an Isotope Production System (IPS) in early 2022, which will deliver and retrieve targets from the reactor core to produce Lutetium-177; a key isotope to be used to treat prostate cancer. After installation, Bruce Power will operate the IPS, which will include packaging irradiated targets for shipment, providing what will be a commercial irradiation service. IsoGen will oversee commercial activities, including communication with the isotope processing facility and procurement of target material for irradiation.





BWXT Medical Ltd.

www.bwxt.com

Product catalogue website:

<https://www.bwxt.com/what-we-do/medical-isotopes>

Contact:

Michael Flagg, Director of Strategic Supply
and Business Development

mflagg@bwxt.com

408-202-1028

Medical isotopes and radiopharmaceuticals sold:

- Indium-111 (Oxyquinoline Solution and chloride)
- Iodine -123 (Sodium Iodide)
- Strontium-82 (Chloride)
- Germanium-68

In development: Technetium-99m generators

BWXT Medical is an experienced manufacturer and supplier of critical medical isotopes and radiopharmaceuticals for research, diagnostic and therapeutic use. Its primary production facilities are in Ottawa (Kanata) and Vancouver and its customers include radiopharmaceutical companies, hospitals and radiopharmacies. BWXT also produces and ships TheraSphere™ for Boston Scientific Corporation. TheraSphere™ is a sterile, active implantable Class III medical device used to treat liver cancer.

The Ottawa facility has a demonstrated track record for safety, regulatory and quality compliance and manufactures custom radiopharmaceuticals and medical isotopes in an 80,000-ft² cGMP/ GLP manufacturing facility that includes a full complement of hot cells (15+) and suites in the Radiochem manufacturing area. Since 2018, BWXT Medical has significantly expanded its workforce from approximately 120 to approximately 200 skilled professionals. The company plans to continue to add more local skilled jobs as new and innovative products are developed for the medical industry. Continued growth is backed by BWXT Medical's parent company and both anticipate a long future in Ottawa and Vancouver.

The Vancouver facility produces diagnostic medical isotopes to enable the detection of infection and to assist with medical procedures, using a commercial cyclotron facility. The Vancouver operations are licensed by the Canadian Nuclear Safety Commission and are located on the TRIUMF site within the University of British Columbia campus. BWXT Medical's collaboration with TRIUMF dates back to 1978 and its commercial cyclotron facility at TRIUMF was completed in 2003. The facility includes:

- preferred access to TRIUMF's 500MeV cyclotron (world's largest)
- three radiochemical annex laboratories, 15 production hotcells, a finished radiopharmaceutical suite and two research hotcells
- one single beam CP-42 cyclotron (30MeV) and two TR-30 dual beam cyclotrons (30MeV).

BWXT Medical and its precursor organizations have been leading innovators in the use of medical isotopes and radiopharmaceuticals and this innovation continues. In 2018, it announced its innovative technology to produce Molybdenum-99 (Mo-99), the parent isotope of Technetium-99m (Tc-99m), which is used in over 40 million diagnostic imaging procedures every year to diagnose cancer, coronary artery disease and other adverse medical conditions. Manufactured molybdenum targets from BWXT's facility in Peterborough will be irradiated in a commercial nuclear reactor (Ontario Power Generation's Darlington Nuclear Generating Station) resulting in the production of Mo-99. The Ottawa facility will process the Mo-99 and manufacture Tc-99m generators, which will then be transported to hospitals and radiopharmacies across North America. Pending approval from FDA and Health Canada, BWXT Medical expects to provide a stable, reliable, long-term supply of Tc-99m, supporting the growing demand for diagnostics across the continent for many years to come.



Canadian Isotope Innovations Corporation

www.isotopeinnovations.com

Contact:

www.isotopeinnovations.com/contact/

306-668-5800

Medical Isotopes Supplied:

- Low specific activity Mo-99
- High specific activity Cu-67

Canadian Isotope Innovations Corporation (CIIC) is a Canadian-controlled private company established in 2015 to produce and sell medical isotopes to nuclear pharmacies and nuclear medicine clinics in Canada and around the world. CIIC has created an innovative, clean and safe method to produce medical radioisotopes. The approach is trailblazing and responsive to global trends on production technologies, customer preferences, and governmental decisions.

Using an electron linear accelerator (LINAC), CIIC has developed the first commercially viable alternative to current reactor-based Mo-99 production. The CIIC LINAC approach does not use uranium or produce significant long-term radioactive by-products, eliminating nuclear proliferation concerns and minimising nuclear waste. The result provides a reliable eco-friendly supply of radioisotopes to the nuclear medicine community.

CIIC currently leases and operates a pilot production facility with a dedicated LINAC. CIIC also uses special laboratories nearby for development work on processes supporting LINAC medical isotope production. CIIC has completed the development and business plan wherein these initial facilities will be used to secure regulatory approval of electron LINAC-produced Mo-99 and Cu-67, delivering these products to CIIC's first customers. As market acceptance of LINAC-produced Mo-99 and Cu-67 develops, additional production facilities will be built to meet demand.



Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Canadian Nuclear Laboratories

<https://www.cnl.ca/>

Contacts:

Ram Mullur
Vice-President
CNL Isotope Business
ram.mullur@cnl.ca

Peter D'Amico
Director Business Development, Isotopes & Health
peter.damico@cnl.ca

Marie-Claude Gregoire
Head of Directorate, Isotopes, Radiobiology & Environment
marie-claude.gregoire@cnl.ca

Canada's premier nuclear science and technology organization offers unique facilities and over 70 years of industry experience

The Chalk River Laboratories represent the largest single complex within Canada's science and technology infrastructure. The site, owned by Crown corporation Atomic Energy of Canada Limited and managed by Canadian Nuclear Laboratories (CNL), contains several licensed nuclear facilities and more than 50 other unique research amenities and infrastructure. The site supports key nuclear science and technology priorities: innovation for industry, safety, security, environmental, clean energy, health and isotope technologies.



Highly skilled employees deliver a range of services – from research and development, design and engineering to specialized technology development. CNL's blend of people, tools and technologies are unmatched in Canada, and in many cases, the world.

Perhaps best known for supplying the nuclear medicine industry with radioisotopes for over seven decades, the team at the Chalk River Laboratories have contributed to over a billion medical procedures globally. What you may not know is that CNL's researchers also perform cutting-edge research in isotope processing, purification and radiolabelling, targeted radionuclide therapies, internal dosimetry, stem cell technology, and the effects of low-dose radiation.

Scientists at CNL are working on the development of advanced life-saving treatments that harness the power of nuclear science and radioisotopes to achieve unprecedented levels of precision in beating cancer. This work includes the production of a promising new weapon in the fight against cancer — Actinium-225 — a radioisotope so rare that the annual global production is less than a grain of sand.

CNL is an active participant in the Targeted Alpha Therapy (TAT) research area. TAT involves combining the destructive potential associated with alpha-emitting radionuclides with biological targeting vectors that deliver a cytotoxic payload to the diseased cells, limiting radiation exposure for healthy cell in vivo. Ac-225 is an alpha-emitting radionuclide having desirable physical decay characteristics.

One of the challenges in conducting clinical trials or even basic research in targeted alpha therapy is the limited availability of the isotopes, in particular, actinium 225. CNL is able to make a significant amount of pure actinium 225 which is use in CNL's research and shared with other collaborators across Canada and around the world.

CNL is Canada's premier nuclear science and technology laboratory, dedicated to developing peaceful and innovative applications from nuclear technology through expertise in physics, metallurgy, chemistry, biology, and engineering. We address global issues across the nuclear lifecycle – reactors and fuels, waste management, nuclear safeguards – and develop novel medical isotopes and devices.

AECL/CNL Select Scientific Achievements:

YEAR	SELECT ACHIEVEMENT/HIGHLIGHT
1945	Zero Energy Experimental Pile Reactor (ZEEP) is the first reactor to operate outside the United States.
1947	National Research Experimental Reactor (NRX) goes online. A major mission was producing isotopes including the first ever, cerium 144, was shipped to the University of Saskatchewan.
1949	Routine production of iodine 131 for pharmaceutical use along with phosphorous 32 and sulfur 35 for R&D.
1950	A meeting involving international experts was held at Chalk River Campus to develop standards for radiological protection. After this meeting the International Commission on Radiological Protection (ICRP) was founded.
1951	World's first megavoltage cancer treatment was delivered with an external beam radiotherapy system developed by and using cobalt 60 from Chalk River.
1957	National Research Universal Reactor (NRU) goes online at Chalk River Campus. Isotopes produced in this facility have led to more than 1 billion treatments and scans worldwide.
1970	First Molybdenum 99 produced in NRU. NRU would produce enough Mo-99 for over 400 million scans.
1991	Creating jobs and new companies, CRL completes its most successful commercial spinoff, Nordion, sale to MDS Inc.
1998	Biological Research Facility, a globally unique low dose radiation animal research facility is commissioned.
2003	BRF advances use of radiation and isotopes by demonstrating low dose gamma radiation reduces tumor latency times in mice.
2014	BRF develops use of low-dose radiation to enhance the performance of stem cells.
2020	Developing next generation isotope production, CNL begins commercial sale of actinium 225 while the Biological Research Facility contributes to pre-clinical and toxicology studies for use of next generation isotopes like Ac-225 and Lu-177.

Over 70 years, a total of sixty different isotopes were produced at Chalk River.



9,000 ACRE SECURE SITE

The Chalk River Laboratories have all of the regulatory, safety, security, utility services and scientific infrastructure in place to enable the timely licensing, construction and testing of advanced nuclear reactor prototypes.



LICENCED NUCLEAR FACILITIES

CNL offers a full complement of facilities to our customers and stakeholders, ranging from fuel development and fabrication, hot cells, surface and materials science, hydrogen isotopes laboratories, to radiation biology.



3,000 EMPLOYEES

Including 500 PhDs, 1,600 engineering, scientific and technical staff to address global challenges in health and the environment with world-class research.

Research & Innovation:

In addition to radioisotope production, CNL also maintains the capabilities to conduct biological research to explore the possibilities of TAT. Our first TAT pre-clinical (in vivo) research study was initiated in the Biological Research Facility to examine the targeting efficiency and anti-tumour efficacy of specific actinium-225 labelled targeting vectors on human breast cancer cells.

The Biological Research Facility is a unique facility which holds the necessary capabilities to conduct TAT-related research. The BRF is currently pursuing Good Laboratory Practice recognition, has ISO 9001 certification, Good Animal Practice certification from the Canadian Council on Animal Care and is staffed by a team with significant experience in radiobiology and radiochemistry.

**RADIOCHEMISTRY & SUPPORTING SERVICES
PRE-CLINICAL & SUPPORTING SERVICES**

- Radiolabeling, any isotope (including but not limited to Ac-225, Bi-213, Pb-212, At-211, Lu-177, In-111, etc.), to DOTA or macropa conjugated peptides, proteins or another commercially available or proprietary Bifunctional Chelators
- Conjugation of DOTA or macropa onto antibodies, including freeze drying of purified conjugated protein
- Development of radiolabeling conditions, based on labeling buffer, pH, effective BFCA concentration
- Determination of effective specific activity and labeling of radionuclide to that target ESA
- Characterization by radio-TLC, and radio-HPLC (C-18 or SEC), including fraction collection
- Crude material purification by SEC, MW cut-off filters and spin columns to provide purified labeled material
- Determination of chemical purity by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or OES and size analysis
- Experienced in evaluation/validation of newly developed probes/molecules
- Animal disease/research model development: xenografts, allografts, and other solid cancer models

PRE-CLINICAL & SUPPORTING SERVICES

In vitro

- Cytotoxicity
- Stability testing
- Purity/size analysis of conjugated antibodies
- Antibody internalization kinetics
- Imaging
- Immunoreactivity/binding efficiency

In vivo

- Efficacy
- Biodistribution
- Biokinetics and internal dosimetry of radionuclides, particularly alpha-emitters
- Dosimetry
- MTD
- Radiotherapy (i.e., TAT, immune check point)
- Cancer model/tumor establishment (mice & rat)
- Tissue/organ processing methods as well as radiochemical processing and analysis of hard-to-detect radionuclides

Work With Us!

CNL serves the nation as an enabler of business innovation and technology transfer, and, by fostering the development of highly-qualified people for the knowledge economy to come.

CNL is proud to work with members in industry, in our supply chain, and in the research community to support the diverse innovation needs within Canada's community of nuclear and radiation science and technology.

**The Centre for Probe Development
and Commercialization (CPDC)**

www.imagingprobes.ca/

Product catalogue: [www.imagingprobes.ca/services/
radiopharmaceutical-manufacturing](http://www.imagingprobes.ca/services/radiopharmaceutical-manufacturing)

Contact:

Owen Roberts
Chief Executive Officer
owen@cpdc.ca

Medical Isotopes supplied:

- no-carrier added Lu-177 as a GMP-grade medical isotope provided in solution ready to use in GMP manufacturing.

The Centre for Probe Development and Commercialization (CPDC) was founded in 2008 at McMaster University with the mandate to generate reliable and cost-effective access to radiopharmaceuticals. CPDC has since become a renowned leader in GMP manufacturing of complex radiopharmaceuticals for just-in-time delivery with international distribution. Recently, CPDC announced a collaboration agreement with Isotopia Molecular Imaging Ltd for the production of GMP-grade no-carrier-added (nca) Lu-177, a well-known and widely used medical isotope.

CPDC also offers a range of services starting with the supply of medical isotope to GMP manufacturing and global distribution of radiopharmaceuticals for clinical trials and including:

- sales of nca Lu-177
- development and GMP validation of radiolabeling processes and methods for radiopharmaceuticals
- GMP manufacturing in support of clinical trials
- regulatory affairs consulting for radiopharmaceuticals
- logistics services for international delivery of radiopharmaceuticals
- clinical trial management.

CPDC is a non-for-profit organization created as a Centre of Excellence for the Commercialization of Research (CECR) funded by the Network of Centre of Excellence (NCE). Since its inception, CPDC has spun out Fusion Pharmaceuticals and created two joint ventures, CanProbe with the University Health Network (UHN), a non-for-profit company focused on the development and production of imaging agents, and ARTMS with Lawson Research Institute, British Columbia Cancer Agency and TRIUMF, a company developing and marketing solid target hardware solutions for cyclotrons. CPDC is currently working at establishing commercial manufacturing capabilities for the GMP manufacturing and distribution of marketed radiotherapeutics.



Sale and Supply
of nca Lu-177



Development and
Validation of
Radiopharmaceuticals



GMP Manufacturing
in Support of
Clinical Trials



Clinical Trial
Management and
Regulatory Support



Commercialization and
Logistics Services for
International Delivery

Isogen

www.isogen.ca

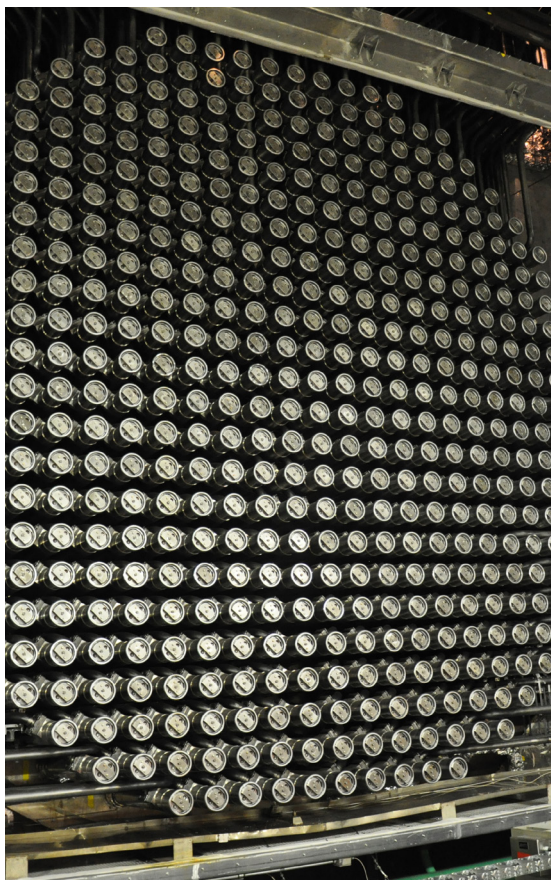
Contact:

Travis Besanger
416-805-4668

info@isogen.com

Isogen is a joint venture between Framatome and Kinectrics, whose mission is to enable the use of CANDU reactors to produce the medical isotopes needed to treat and diagnose patients with serious diseases world-wide. Isogen's enabling partnership with Bruce Power allows us to produce the world's largest and most reliable supply of lifesaving, short-lived, medical isotopes.

Isogen provides commercial isotope irradiation services to isotope processors and radiopharmaceutical drug developers and manufacturers.



Isologic Innovative Radiopharmaceuticals Ltd.

www.isologicradiopharm.ca

Website orders: www.isologicradiopharm.ca/web-orders

Contact:

514-636-4711

info@isologicradiopharm.ca

Medical Isotopes Supplied:

SPECT and Iodine Products:

- Iodine-Diagnostics and Therapeutic
- Technetium-99m (Sestamibi, Gluceptate, MDP, Mag, MAA, DTPA, Tetrofosmin, Sulfur Colloid, DMSA, ECD and HMPAO)
- Indium-111& Ceretec WBC labeling
- Biscitate
- Thallium-201 Cardiac
- Gallium-67
- Sodium Technecium 04

PET Products:

- Fluorine-18 (FDG, Sodium Fluoride & Florbetaben)
- Gallium-68 (PSMA, Dotatate)

Isologic Innovative Radiopharmaceuticals (ISOLOGIC) is a nationwide radiopharmaceutical company, dedicated to nuclear medicine and the science of Radiopharmaceutical production. Our commitment to these fields extends to the communities we serve. We have over 170 team members focused on serving our customers and their patients. We utilize our significant experience, expertise and networks in nuclear pharmacy to provide our customers and patients with reliable, safe and high-quality radiopharmaceutical products and services.

Isologic's objective is to be a global leader and be the central point of entry for breakthrough radiopharmaceuticals in Canada, supplying to hospitals and private clinics across Canada.

Isologic is a leading advocate for better patient care. Recognized as the most Trusted Quality Care partner, ISOLOGIC is dedicated in providing leading innovations and solutions to Canadian practitioners, while returning attractive financial results for the organization that is committed in reinvesting in the field.



isoSolutions

www.isosolutions.com

Contact:

Arun Singh

asingh@isosolutions.com

604-669-7277

Medical Isotopes Supplied:

- C-14,
- I-123
- I-131
- Sr-89
- Tl-201
- Cu-67
- Cu-64
- Ga-67
- I-124
- Lu-177 (ca, nca)
- Sr-89
- In-111
- I-125
- Mo-99
- Zr-89
- Am-241
- Y-90

Based in Vancouver, B.C., isoSolutions provides a one-stop shopping service as well as technical support worldwide for nuclear medicine applications including radiochemicals, stable isotopes, labelled compounds, sealed sources, synthesizers and peptides.

isoSolutions provide a complete range of radioisotopes, including a Ga-68 Generator, Lu-177, Y-90, I-131, I-125, and cyclotron products. These products are complemented by an automated labeling module for development work or preprogrammed syntheses and a complete line of quality control instruments. isoSolutions is the exclusive distributors of Elysia-Raytest in the U.S. and Canada. It also offers consulting services for radiochemistry, grant applications and licensing (CMC sections, INDs, DMFs) in several regions across the globe.

With dedicated sales and marketing teams in key markets, and a logistics and technical team well-versed with global requirements, isoSolutions is positioned to manage the supply chain complexities involved with securing and transporting nuclear medicine products to all corners of the world. It has partnered with local companies in key markets to take care of local regulations, thereby ensuring that nuclear medicine products reach the end users quickly.

isoSolutions also provides stable isotope targets including B-11 Gas, B-10, Cd-112, Ge-74, Li-7, Mo-100, N-15, O-17 Gas, O-17 Water, O-18 Water, Te-124, Xe-124, Xe-129, Zn-64.



isotopia

Isotopia Molecular Imaging Ltd.

www.isotopia.co.il

Contact:

Keren Moshkoviz

Kmoshkoviz@isotopia.co.il

info@isotopia.co.il

972-54-8182398

Medical Isotopes Supplied:

- Lutetium-177

Isotopia is a radio-pharmaceutical company established in 2006 to serve the nuclear medicine field and focus on theragnostic applications. Since then, it has become an essential supplier for the growing field of nuclear medicine and theranostics globally. It was founded by a highly trained group of senior professionals, experienced in all aspects of radio-pharmaceutical operations, in collaboration with a group of Canadian investors.

Isotopia's experienced and highly skilled team created a unique platform consisting of a centralized radiopharmacy, sterile manufacturing plant for cold kits, and an isotope production site. This structure provides a sound platform for research and development

initiatives and successful commercial activities. Isotopia operates a PETtrace 16.5MeV Cyclotron (GE Healthcare), supplying both PET and SPECT tracers, manufactured under strict quality control procedures.

The vision of Isotopia is to become a significant player in the future of radiotherapeutics that meets the patient needs worldwide. Isotopia is supporting the progress in the field of molecular imaging and radiotherapy with innovation and real time awareness to emerging techniques that improve diagnosis and optimal therapy in various health landscape. As of now, Isotopia is taking steps for becoming a major worldwide supplier of Lu-177 (ca and nca) under GMP condition to be used in the field of molecular radiotherapy. Isotopia and CPDC are establishing Canadian production of Lu-177 nca to serve the Canadian and North American markets, while supporting the development and manufacturing of important radiopharmaceuticals. Lu-177 nca is produced from highly enriched Yb176 and processed in unique method developed by Isotopia under GMP conditions. It is also used with various vectors to treat cancer under several clinical studies. Isotopia and CPDC aim to support the radiopharmaceutical development, supply to clinical research and for radiolabeling on site at hospitals.



McMaster University Nuclear Operations and Facilities

www.nuclear.mcmaster.ca

Contact:

Reactor@mcmaster.ca

Medical Isotopes Supplied:

Medical Isotopes (shipped routinely):

- Iodine-125 (60d)
- Lutetium-177 (6.7 d)

Other Isotopes (available upon request):

- | | |
|--------------------------|---------------------------|
| • Sodium-24 (15 h) | • Holmium-166 (27 h) |
| • Antimony-124 (60 d) | • Arsenic-77 (39 h) |
| • Silicon-31 (2.6 h) | • Thulium-170 (130 d) |
| • Cesium-134 (2 y) | • Selenium-75 (120 d) |
| • Phosphorus-32 (14 d) | • Ytterbium-169 (32 d) |
| • Lanthanum-140 (40 h) | • Bromine-82 (35 h) |
| • Potassium-42 (12 h) | • Ytterbium-175 (4.2 d) |
| • Cerium-140 (32 d) | • Rubidium-86 (19 d) |
| • Scandium-46 (84 d) | • Hafnium-181 (42 d) |
| • Promethium-147 (2.6 y) | • Strontium-85 (65 d) |
| • Chromium-51 (27 d) | • Tantalum-182 (115 d) |
| • Promethium-149 (53 h) | • Strontium-89 (50 d) |
| • Manganese-56 (2.6 h) | • Tungsten-187 (24 h) |
| • Samarium-153 (47 h) | • Yttrium-90 (60 h) |
| • Cobalt-58 (71 d) | • Rhenium-186 (89 h) |
| • Europium-152 (12.7 y) | • Molybdenum-99 (66 h) |
| • Cobalt-60 (5 y) | • Rhenium-188 (17 h) |
| • Europium-154 (8.5 y) | • Ruthenium-103 (39 d) |
| • Nickel-63 (100 y) | • Iridium-192 (74 d) |
| • Gadolinium-153 (242 d) | • Rhodium-105 (35 h) |
| • Copper-64 (12 h) | • Iridium-194 (19 h) |
| • Gadolinium-159 (18 h) | • Silver-110m (250 d) |
| • Zinc-65 (265 d) | • Gold-198 (2.7 d) |
| • Terbium-160 (72 d) | • Cadmium-109 (453 d) |
| • Gallium-72 (14 h) | • Thallium-204 (3.8 y) |
| • Terbium-161 (7 d) | • Antimony-122 (2.7 d) |
| • Arsenic-76 (26 h) | • Protactinium-233 (27 d) |

The McMaster University reactor is a versatile radioisotope production facility capable of producing a wide range of radioisotopes not listed. Please contact us for questions regarding these isotopes or others not listed.

Cyclotron produced isotopes to be offered in 2021:

Zr-89, Ga-67, F-18

All isotopes are prepared at the McMaster Nuclear Reactor, processed on site from the target material and shipped in Type A packages.

McMaster University, a Canadian leader in nuclear science, houses an integrated suite of research facilities that enable discoveries in medicine, clean energy, nuclear safety, materials, and environmental science. Collectively, the **Nuclear Operations and Facilities (NO&F)**, consists of the following infrastructure:

- The **McMaster Nuclear Reactor (MNR)** – a multi-purpose reactor that provides neutrons for research and medical isotope production.
- The **Centre for Advanced Nuclear Systems (CANS)** – a post irradiation examination for analyzing highly radioactive materials
- The **High-Level Laboratory Facility (HLLF)** – a laboratory licensed for research into medical uses of radioisotopes.
- The **McMaster Accelerator Laboratory (MAL)** – three particle accelerators and a large volume gamma irradiator.
- The **McMaster University Cyclotron Facility (MUCF)** – a 16 MeV cyclotron and hot cell suite for research and the manufacturing of radiopharmaceuticals for clinical use.

McMaster University's nuclear facilities are owned and operated by McMaster University. As one of the country's leading research-intensive universities, McMaster is committed to research excellence in all areas, including operation of the nuclear facilities. It is also committed to the global supply of medical isotopes with a focus on strong customer service and reliable supply.

The products are produced from either the reactor or the cyclotron. In addition to irradiation services, we have a large licensed laboratory space equipped with large industrial hot cells, pharmaceutical grade hotcells, fume hoods, glove boxes, clean rooms (for GMP production of radiopharmaceuticals) and trained scientific staff to support the development and commercialization of medical isotopes and their uses.



Nordion

www.nordion.com

Contact:

Richard Wiens
Director, Strategic Supply
richard.wiens@nordion.com
613592-3400 x 2699

Medical Isotopes Supplied:

- Cobalt-60 sources

Nordion is a leading global provider of Cobalt-60 used in the sterilization and irradiation processes for the medical device, pharmaceutical, food safety, and high-performance materials industries, as well as in the treatment of cancer. Nordion supplies products to more than 40 countries around the world.

We are the leading global provider of Co-60 sealed sources and gamma irradiators, which are key components to the gamma sterilization process. Co-60 is a radioactive isotope that is needed by medical device manufacturers and sterilizers. Co-60 decays and must be replaced over time to produce the desired level of irradiation. We have the most comprehensive access to nuclear power reactor operators around the world which are able to produce Co-60.

The capabilities that we provide to Nordion's customers include handling and processing of Co-60, recycling of depleted sources and global logistics enabled by our licensed container fleet. We are integral to our customers' operations due to highly coordinated and complex installation processes. In addition, we are a leading supplier of Co-60 sources for stereotactic radiosurgery devices (such as the Gamma Knife®), which are used for certain oncology applications.

Ontario Power Generation

www.opg.com

Contact:

Terry Campkin
Sr. Manager Isotope Sales
Terry.campkin@opg.com
289-388-9029

Medical Isotopes Supplied:

- Tritium

Ontario Power Generation (OPG) is proud to be one of the largest, most diverse clean power producers in North America, investing millions in local economies and employing thousands of people to maintain a modern, sophisticated energy fleet. OPG operates 10 nuclear power plants at two stations, Pickering and Darlington, as well as a tritium recovery facility.

OPG sells tritium directly to users and utilizes its reactors to irradiate targets for other isotope producers, notably for the production of Cobalt-60 which is then processed and sold by Nordion. It is also investigating the use of its reactors to irradiate proprietary targets for BWXT to support production of their Technetium-99m generators and is interested in developing similar relationships with other producers.

Laurentis Energy Partners is a subsidiary of OPG that provides technical services and is working with BWXT to develop their novel approach to Technetium-99m supply.



Sylvia Fedoruk Canadian Centre for Nuclear Innovation, Inc (The Fedoruk Centre)

www.fedorukcentre.ca

Contact:

Lidia Matei
 Corporate Business Officer
Lidia.matei@fedorukcentre.ca
 306-966-3379

Medical Isotopes Supplied:

- F-18 (various labelled compounds, liquid, dose);
- C-11 (CO₂, gas)
- Zr-89 oxalate (Investigational Active Pharmaceutical Ingredient or radiochemical, liquid),
- N-13 (ammonia, gas)
- Cu-64 (irradiated solid target)

The Fedoruk Centre is a not-for profit organization established in 2011 with the purpose to place Saskatchewan among global leaders in nuclear research, development and training through investment in partnerships with academia and industry for maximum societal and economic benefit. It operates and manages the Saskatchewan Centre for Cyclotron Sciences (SCCS), a Class II nuclear facility that is owned by the University of Saskatchewan and licensed by the Canadian Nuclear Safety Commission (CNSC) to produce and handle a wide range of isotopes. As well as providing medical isotopes to customers, it conducts research and development of new imaging probes, completes preclinical studies, performs imaging experiments in plants and soils and advances products towards clinical trials.

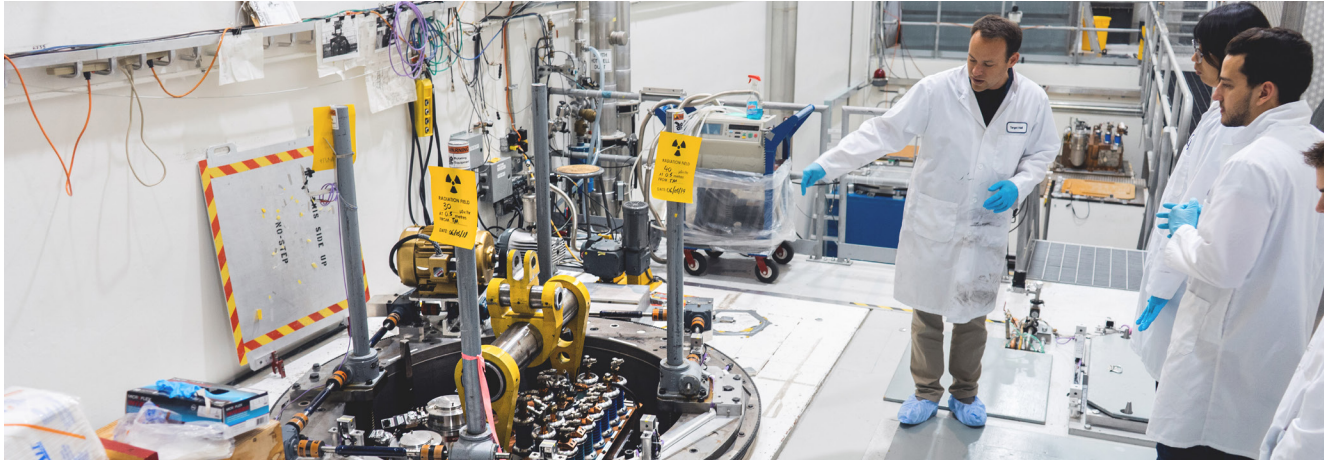


The SCCS is equipped with a medium energy (24MeV) cyclotron designed to produce a large range of radioisotopes. The accelerator operates in the range of energy 18-24 MeV with currents up to 500microA. The system is equipped with one beam line and a high-power target station used to produce multi-Curie amounts of radioisotopes. Three liquid targets, a gas target and a target selector for solid targets are also installed on the machine. Specialized radiochemical and radioanalytical workstations allow for the synthesis, separation, purification, and characterization of radiolabeled compounds. Environmentally controlled clean space is available for developing radiotracers in conditions compliant with Good Manufacturing Practices (GMP).

The SCCS houses equipment suitable for validating new therapeutic molecules and imaging agents through 'in vitro' and 'in vivo' experiments. The cell culture laboratory accommodates the growth of cell lines needed for a study. Small animal SPECT/CT, and PET/CT imaging equipment are available to evaluate the response in animal models. Radiation counters and detectors for alpha, beta and gamma radiations are available for use in biodistribution studies

The BioPETx detector — the first of its kind in Canada — is used to study plants and soil under various conditions and detect responses to stressors such as drought, infections, and insect infestations. Growth chambers are available to control environmental conditions and safely house dosed plants.

The Fedoruk Centre holds a Drug Establishment License (DEL) issued by Health Canada to produce fluorodeoxyglucose (FDG) as a marketed drug product at the SCCS. Our highly qualified staff members are ready to assist in validating GMP compliant procedures and conducting Quality Control testing.



TRIUMF

www.triumf.ca

Contact:

Sean Lee
Head, External Relations
seanlee@triumf.ca
604-222-7655

Established in 1968 in Vancouver, TRIUMF is Canada's particle accelerator centre. Home to several cyclotron and linear accelerators, the laboratory is a hub for discovery and innovation inspired by a half-century of ingenuity in answering some of nature's most challenging questions. From the hunt for the smallest particles in the universe to the development of new technologies, TRIUMF is pushing frontiers in research, while training the next generation of leaders in science, medicine, and business.

From its inception, the Life Sciences program at TRIUMF has leveraged the laboratory's extensive particle accelerator expertise and infrastructure to develop novel technologies that help understand life at the molecular level. Since the 1980s, TRIUMF has enabled the production of short-lived positron emitting isotopes – such as Carbon-11 (C-11), Fluorine-18 (F-18) and Nitrogen-13 (N-13) and corresponding radiopharmaceuticals utilizing these isotopes – in support of collaborations with the University of British Columbia, BC Cancer, and other key partners. Today, research continues into novel radiochemical synthesis methods to produce experimental small molecule radiopharmaceuticals with the aforementioned isotopes, but the program has also evolved into a GMP-capable

initiative that provides doses of more than a dozen tracers for cancer patients, as well as studies on Parkinson's disease and other neurodegenerative conditions.

TRIUMF also has the technology and capacity to produce numerous metallic radioisotopes used for imaging, including the cyclotron-based production of Technetium-99m, Zirconium-89, Copper-64, Gallium-68, and Scandium-44. Further to this, another key area of focus for TRIUMF's medical isotope program is the production of radiometals for therapeutic application; these isotopes, which include Actinium-225 (Ac-225), Bismuth-213, and Lead-212 are produced during high-energy proton-induced spallation of Thorium-232. With the start of many clinical trials involving targeted radionuclide therapy for the treatment of late-stage cancers, TRIUMF has embarked on a production and scale-up program for key isotopes like Ac-225, and other alpha-emitting radioisotopes. Parallel to this work, TRIUMF is also supporting research into and novel applications for certain Auger emitting isotopes, such as Mercury-197 and Antimony-119.

Overall, with the vast range of particle accelerators and radiochemistry facilities available at TRIUMF, the laboratory maintains a large array of isotope and radiopharmaceutical production capabilities.

Isotopes are sold directly by TRIUMF and a subsidiary TRIUMF Innovations provides services that support other producers of medical isotopes.

5 Manufacturers of original irradiation equipment

As Canada pushed the limits of medical isotope development specialist irradiation equipment had to be designed and built. The companies involved have developed that expertise to offer their products and services to other customers. These include:

- ACIC Machinery
- Advanced cyclotron systems (cyclotrons)
- ATS Comecer (target processing systems)
- Mevex (accelerators)

Canadian companies also have the expertise required to support the re-engineering of power reactors to enable target irradiation. These capabilities are included in the supply chain section.



ACIC
MACHINERY

ACIC Machinery

www.acicmachinery.com

Contact:

Eduardo Andrade, General Manager

Eandrade@acic.com

Michael Hughey, Corporate Sales Director

Mhughey@acic.com

ACIC Machinery delivers turnkey equipment and automation solutions for radiopharmaceutical and pharmaceutical manufacturing. ACIC Machinery has extensive experience designing, building, and commissioning both standard and custom projects. ACIC Machinery is a leading provider of:

- Synthesis and dispensing hot cells/shielded isolators integrated with robots or tele-manipulators
- Vial filling
- Capping and crimping
- Particulate matter, cosmetic, and components visual inspection
- Radiation inspection
- Labeling
- Cartoning
- Washing and sterilization lines
- Water treatment (WFI, PSG, storage tanks)

ACIC Machinery works closely with their clients to design and build hot cell solutions that meet the highest levels of operator safety and product quality.



ATS-Comecer

<https://www.comecer.com/>

ATS Industrial Automation and Comecer, part of the ATS group, design and manufacture systems and equipment for the safe treatment of radioactive substances used in nuclear medicine, ensuring minimal exposure for the operator and optimal production throughput and quality. In particular, Comecer is a leader in the field of radiochemistry, where it creates shielding systems for special applications on behalf of large industrial groups, research organizations and radiopharmaceutical organizations.

The completely automated Alceo solid target system is used internationally in the production of radioisotopes, such as ^{68}Ga , ^{123}I , ^{124}I , ^{64}Cu and also ^{89}Zr , ^{45}Ti , ^{61}Cu . This fully automated system is able to deposit the source material on a target, deliver the target to and from a bombardment source and dissolve and purify the radioactive material.

Alceo is composed of three units:

- the irradiation unit, which includes the target itself and related ancillary subsystems
- an automated unit dedicated to electroplating and pneumatic delivery/recovery of the target to/from the cyclotron
- a second automated unit, integrated with the former, used for the dissolution and purification of the produced radioisotopes of interest.

[This video](#) shows step-by-step procedures for the production of radioisotopes (^{64}Cu , ^{89}Zr , and ^{123}I - ^{124}I) using the New ALCEO Solid Target Processing System.



Advanced Cyclotron Systems Inc. (ACSI)

www.advancedcyclotron.com

Contact:

info@advancedcyclotron.com

604-276-1493

Advanced Cyclotron Systems, Inc. (ACSI) is a world leader in the design and manufacturing of cyclotron systems. With over 30 years of experience and more than 60 cyclotron systems installed, ACSI can provide a wide range of equipment and services worldwide. ACSI cyclotrons are used for the commercial production and distribution of PET and SPECT nuclides by internationally recognized companies and leading universities and research facilities. ACSI cyclotrons are designed, manufactured, and assembled in Richmond, B.C., Canada.

ACSI offers a full spectrum of cyclotron systems ranging from PET cyclotrons to medium and high energy accelerators. All ACSI manufactured cyclotrons have variable energy and employ external ion source technology, offering the highest beam current output available on the market.

The versatility, high beam current and exceptional quality of ACSI cyclotrons are the reasons why many of the world's most prestigious universities and research centres, as well as some of the most successful commercial radioisotope producers, have chosen ACSI cyclotrons to meet their radioisotope production needs.



Mevex Corporation

www.mevex.com

Contact:

info@mevex.com

613-831-2664

Mevex Corporation was founded in 1986 just outside Ottawa, Ontario, Canada. The primary objective of the business is the design, manufacture and support of Linear Accelerator systems for many applications around the world. Mevex has supplied over 100 LINACs to many different organizations including radio-isotope production, sterilization of medical devices or food products and R&D applications.

Mevex supplied and supports the CII 35 MeV LINAC in Saskatoon, which is currently being used to develop and produce several types of medical isotopes. This unique design of LINACs utilizes standard lower energy components coupled together to produce the higher energy electron beam needed to create the photonuclear reaction required to produce these unique and valuable medical products in Canada. Mevex also provided an upgrade (to 40 MeV) to a LINAC at Argonne National Laboratory now used for development of several medical isotopes.

Mevex has also been part of several international development programs including working with IAEA on methods of production and distribution of medical isotopes and has a keen interest in supporting the Canadian objective for these valuable and often rare products.

6

Manufacturers of original equipment incorporating medical isotopes

Transporting radioactive materials can be challenging and, as a result, companies using those materials in their products will settle near to where the medical isotopes are produced. Two key international suppliers are based in Canada and benefit from the proximity of the supply and the knowledge developed in the community. These are:

- Best Theratronics (external beam irradiators)
- Nordion (sterilizer plant)

Nordion is also a part of the production pipeline. See their company description in Section 4.



Best Theratronics

www.theratronics.ca

Contact:

Krishnan Suthanthiran

613-591-2100

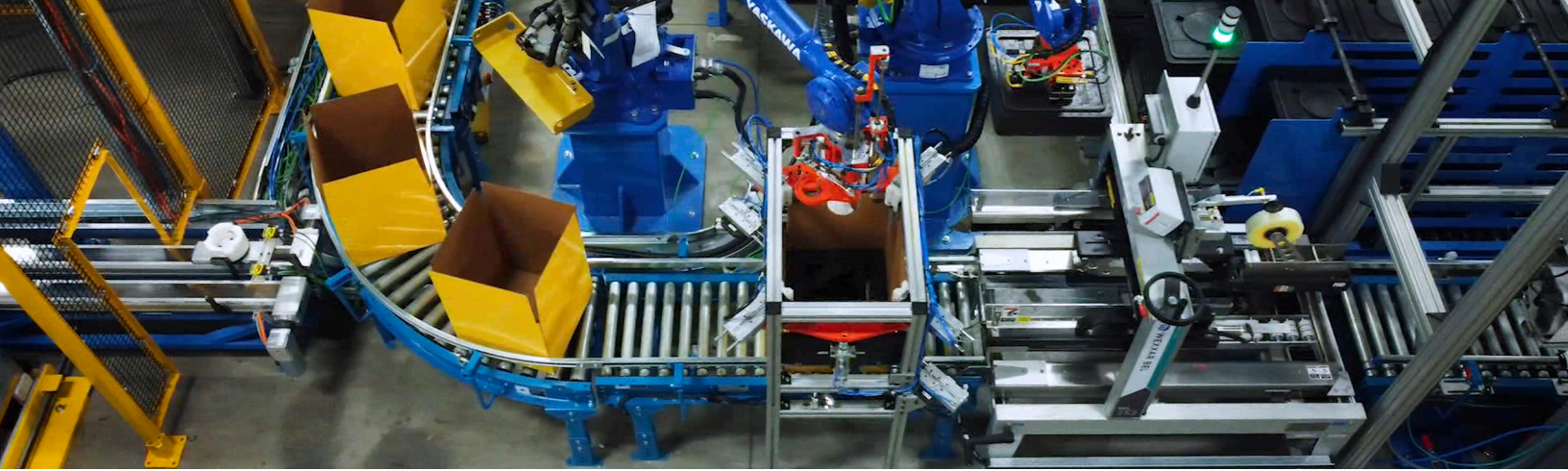
info@theratronics.ca

Best Theratronics Ltd., a Canadian component of TeamBest® located in Ottawa, is a manufacturer of medical equipment used throughout the world. Constantly expanding and innovating, Best Theratronics provides reliable and cutting-edge medical equipment and supplies to the global healthcare and research industries.

Best Theratronics manufactures two distinct product lines using medical isotopes – External Beam Teletherapy Machines and Self-Contained Irradiators. The external beam radiation therapy product lines, Theratron® Equinox™ and the GammaBeam™ use Cobalt 60 to provide advanced therapies to cancer patients worldwide. Best

Theratronics also manufactures irradiators used for blood irradiation and research. These include the Cesium-137 based Gammacell® blood irradiators, the X-ray based Raycell blood irradiators, and the Cobalt-60 Gammabeam™ X200 research irradiator. Each model is available in a variety of source configurations based on customer throughput requirements. Along with Best Cyclotron Systems, another member of the TeamBest Companies, Best Theratronics offers a range of proton cyclotrons (15, 20, 25, 30, 35 and 70 MeV) with highly advanced, state-of-the-art technologies, for research, diagnostic and therapy isotope production.

As a leader in innovative technology, Best Theratronics continues to uphold an excellent reputation in the health care field by working with medical professions to develop, manufacture, and deliver cost-effective, high quality products to benefit patients worldwide.



7 Suppliers of goods and services used in the production of medical isotopes

THE SUPPLY CHAIN

Whether it is legal services, engineering, equipment supply, consumables or logistics the medical isotope ecosystem is supported by specialist suppliers, which benefit from the proximity to each other. Those companies supplying to the ecosystem that are either member of CNIC or OCNI are listed here.

- Alithya
- Artms
- Anvil International
- ATS Automation Tooling Systems Inc.
- Black and McDonald
- Bucephalus Consulting
- Brotech Precision
- Calian Ltd
- Camfil
- CPDC
- DB2 Consulting
- Globotech Inc
- Gowling WLG
- isoSolutions
- Kinectrics
- Laurentis Energy Partners
- Lemo Canada Ltd
- MarShield
- McMaster University Nuclear Operations and Facilities
- New Era Group
- Pacer Air freight
- PLC Fire Safety Solutions
- Promation Nuclear
- RSSC Wire and cable
- Stevcon Packaging
- South West Exposures
- Sylvia Fedoruk Canadian Centre for Nuclear Innovation
- Tam International
- Trillium Flow Technologies
- Tyne Engineering
- Westinghouse Electric Company



Alithya

www.alithya.com

George Halim
416-932-4797

George.Halim@alithya.com

Alithya Group inc. (TSX: ALYA) (NASDAQ: ALYA) ("Alithya"), a leader in strategy and digital transformation, and a trusted supplier to the nuclear industry for more than 30 years has been supporting the Canadian isotope sector with its artificial intelligence, automation, and digital systems expertise.

Services/Products: Detail engineering and testing of the control system for the isotope delivery system, and Designing simulation platforms for the verification and validation of various isotope delivery systems



ARTMS, Inc.

www.artms.ca

Doug Gentilcore
604-228-4016

info@artms.ca

ARTMS is a global leader in solid target technology and our products enable our partners to produce high value diagnostic isotopes.

Services/Products: ARTMS technology enables decentralized production of key diagnostic isotopes like Gallium-68, Zirconium-89, Technetium-99 and Copper-64 in large quantities



Anvil International, LLC Power & Process Division

www.anvilintl.com

Joe Rosca
714-469-0010

jrosca@anvilintl.com

Services/Products: Anvil provides engineering design services for piping/tubing supports and ASME Safety Related and Commercial Grade pipe hangers and supports (e.g. strut, clamps, brackets, etc.).



ATS Automation Tooling Systems Inc.

www.atsautomation.com

Joseph Tam
647-302-9058

jtam@atsautomation.com

ATS Automation develops and manufactures high-tech customized systems for nuclear facilities generating medical isotopes to the radio pharmaceutical organizations production and dispensing facilities worldwide. With full validation testing and adherence to latest GMP and nuclear quality standards, we are a trusted partner in all stages of the medical isotope supply chain.

Services/Products: Nuclear Medicine Shielded Equipment for Synthesis, Dispensing and Injection. GMP Radiopharmacy shielded hot cells and laminar flow isolators for dispensing radiopharmaceuticals in nuclear medicine.



Black & McDonald

www.blackandmcdonald.com

James Whyte
905-999-3257
jwhyte@blackandmcdonald.com

Black & McDonald is a privately owned and operated Canadian company which was established in 1921. Having a long-standing presence in the Canadian nuclear industry as an Engineer, Procure and Construct (EPC) contractor.

Services/Products: Black & McDonald has successfully delivered over 525 projects (EPC) for OPG Darlington, OPG Pickering, OPG Western Waste Management Facility, Bruce Power, CNL Chalk River and Point Lepreau.



BUCEPHALUS
CONSULTING
Taking You To New Territories

Bucephalus Consulting

Neil Alexander
639-470-1516
alexander.neil51@gmail.com

Bucephalus Consulting provides management consulting services to the Canadian nuclear industry specializing in isotope production and sales, small modular reactor deployment, decommissioning and waste management and the Canadian nuclear supply chain.

Services/Products: Typical projects include market studies, business plan development, supply chain studies and marketing advice including strategy development for proposals and grant applications.



Brotech Precision CNC Inc.

www.brotechprecisioncnc.com

Jerome Horowitz
416-123-4567
jerome@brotechprecisioncnc.com

Brotech is an ultra-high precision manufacturer and supply chain partner for metal components to critical industries.

Services/Products: For the isotope industry, it manufactures metal casings of many sizes, which are used to package the isotope in its delivery to customers.



Calian Ltd.

www.calian.com
Hani Al Anid
613-599-8600
h.alanid@calian.com

Calian Nuclear is a centre of excellence for the development of technological safety and risk-based solutions. With significant expertise in performing nuclear safety assessments and knowledge of nuclear regulatory systems, Calian helps radioisotope producers develop a licensing strategy and provides support throughout its execution.

Services/Products: Calian Nuclear has expertise in supporting regulatory activities, developing safety analyses, assessing environmental risk, and performing technical feasibility analysis related to isotope production.



Camfil

www.camfil.com

Abhishek Arora
905-660-5691
abhishek.arora@camfil.com

Camfil is a leading manufacturer of premium clean air solutions, providing safety and protection systems for air filtration and air pollution controls that improve worker and equipment productivity while minimizing energy and protect the environment. Camfil has been providing solutions for nuclear power plants and isotope manufacturers since the early-1960s.

Services/Products: Camfil manufactures specialized air filtration equipment and air filters used in the manufacturing process of isotopes.



Centre for Probe Development and Commercialization

<https://www.imagingprobes.ca/>

Owen Roberts
owen@cpdc.ca

CPDC was founded in 2008 with the mandate to generate and cost-effective access to radiopharmaceuticals. It has become a renowned leader in GMP manufacturing of complex radiopharmaceuticals for distribution internationally. CPDC has a solid book of business and pipeline of global customers and has successfully spun out three companies, including Fusion Pharmaceuticals.

Services/Products: Since its inception, CPDC has become the go-to source for the manufacturing and just-in-time delivery of radiopharmaceuticals, including diagnostics and therapeutics.



CMNA
CANADA METAL NORTH AMERICA

Canada Metal North America Ltd.

www.canadametal.com

Richard Hall
514-327-2011-EX 210
rhall@canadametal.com

Services/Products: Lead shielding for Universal Transportation Containers.



DB2 Consulting Inc.

www.db2consulting.ca

Doug Burton
289-251-1105
doug@db2consulting.ca

DB2 Consulting provides business development services in the isotope field. It provides sales and consulting services with isotopes and their production equipment for over 10 years.

Services/Products: Services provided include domestic and international isotope business development.



Globotech Inc.

www.globotech-inc.com

Hossein Zand
416-705-9263
hossein.zand@globotech-inc.com

Globotech Inc. was established in 2008 as an engineering company that mainly focuses on electrical, instrumentation, control and automation, mechanical, structural and environmental engineering activities, along with risk management and analysis, bring a comprehensive approach to the projects and clients' needs.

Services/Products: To provide the highest quality engineering deliverables in the most cost-effective manner and within the desired time schedule to meet client requirements.



isoSolutions

<https://isosolutions.com/>

Arun Singh
604-669-7277
asingh@isosolutions.com

isoSolutions Marketing & Management Inc. offers a wide range of products for nuclear medicine applications, from a variety of reliable suppliers, providing a one-stop shopping service as well as technical support.

Services/Products: Radiochemicals, stable isotopes, labeled compounds, peptides, sealed sources, synthesizers, generators, quality control instruments, and technical services.



Gowling WLG.

www.gowlingwlg.com

Ahab Abdel-Aziz
416-814-5608
ahab.abdelaziz@gowlingwlg.com

The Gowling WLG nuclear legal team is at the forefront of the nuclear industry's most innovative medical radioisotope projects. The team's breadth of experience enables them to provide a comprehensive, multi-faceted advisory approach on isotope projects, from early-stage development considerations to project execution matters such as execution strategies and dispute resolution support.

Services/Products: Legal services/licensing advice, regulatory representation, project risk assessment, advice on contract models, project strategy and related legal issues (e.g. tax, environment), negotiation support, and contract drafting.



Kinectrics

www.kinectrics.com

Travis Besanger
416.805.4668
info@kinectrics.com

KINECTRICS

Kinectrics is the category leader in providing lifecycle management services for the nuclear power and electricity industry. Its expertise in engineering, testing, inspection, and certification is backed by its independent laboratory and testing facilities, and a team of over 1,000 engineers and technical experts.

Services/Products: Kinectrics provides engineering, design, safety analysis and licensing services related to reactor-based medical isotope production.



Laurentis Energy Partners

www.laurentisenergy.com

Jennifer Quirt
905-626-9117
quirt.jennifer@laurentisenergy.com

Laurentis Energy Partners is an innovator and leader in the clean energy industry, providing products and services across the sector, including Canadian-made medical isotopes. Established in 2012 as a subsidiary of Ontario Power Generation (OPG), Laurentis is a recognized leader of asset management services for the energy industry, based in Ontario and operating in North America and Europe.

Services/Products: Inspection, maintenance, engineering, project management, training, nuclear-materials transportation, and processing.

Beginning in 2022, Laurentis will provide isotope irradiation services at Darlington NGS supporting production of Molybdenum-99.



MarShield Radiation Shielding

www.marshield.com

Jim Chesla
905-637-3862
jchesla@marsmetal.com

MarShield is a custom manufacturer and supplier of lead, tungsten, and non-lead alternative products and materials to the nuclear medicine/radioisotope industry. We specialize in shielding protection and storage with an emphasis on customization in order to better suit the customer's specific application, with the goal of a safer work environment allowing for improved efficiency.

Services/Products: MarShield specializes in lead-lined cabinets, shielded decay drums and storage, tungsten vials and syringe shields, lead bricks, L-Blocks and caves, glass, acrylic, curtains, and rolling and stationary shields.



LEMO Canada INC.

www.lemo.com

Mario Colacino
905-889-5678
mcolacino@lemo.com

The original push-pull connector, LEMO is the acknowledged leader in the design and manufacture of precision custom connection and cable solutions. LEMO's high quality push-pull connectors are found in a variety of challenging application environments including medical, nuclear, industrial control, test and measurement, audio-video and telecommunications

Services/Products: Manufacturing connectors for the nuclear industry for over 40 years. The nuclear connectors meet stringent requirements of this industry with special grade stainless steel and PEEK materials.



McMaster University Nuclear Operations and Facilities

www.nuclear.mcmaster.ca

Nuclear Operations and Facilities Inquiries
905-525-9140 x24279

McMaster University, a Canadian leader in nuclear science, houses an integrated suite of research facilities that enable discoveries in medicine, clean energy, nuclear safety, materials and environmental science. The anchor facility is the 5 MW research reactor which, amongst other medical isotopes, is the largest producer of Iodine-125, treating 200 patients per day.

Services/Products: R&D, medical isotope production, separation, processing, quality testing, shipping and logistics.



New Era Group

www.neweragroup.co

Anthony Tersigni
416-742-8098
atersigni@neweratool.com

New Era Group has been in business since 1963 and evolved from a Tool & Die company to a highly specialized multi-capability facility supporting oil and gas, turbine and nuclear power. It is ISO9001 certified, CWB471, CSA Z299.2 and N299 approved.

Services/Products: New Era Group can provide fabrication, machining, specialty welding, painting and assembly of complete sub-assemblies up to and including complete equipment and systems.



PLC Fire Safety Solutions

www.plcfire.com

Rudy Cronk
416-123-4567
rcronk@plcfire.com

PLC is an engineering company that specializes in fire protection for the nuclear industry. It provides medical isotope producers with services that ensure the licensed holder is compliant regulatory requirements (fire protection).

Services/Products: Fire hazard assessment, third party reviews, fire protection program audits, code compliance reviews, fire system designs, commissioning services, emergency management, and accessibility assessments.



Pacer Air Freight

www.pacerair.com

Michael Stopay, Director
905-672-7223
mike@pacerair.com

Pacer Air Freight is a global time-critical logistics company that provides customized solutions for the medical isotope industry.

Services/Products: It can assist with shipping and customs clearance of nuclear isotopes used in research, clinical trials, and patient treatment, as well as warehousing and/or packaging services.



Promotion Nuclear

www.promotion.com

Alex Sakuta
416-230-1618
sakuta.a@promotion.com

Promotion Nuclear combines its long history of manufacturing automation with its respected expertise in the nuclear industry to provide the Canadian isotope ecosystem with custom solutions for the production, processing, packaging, distribution, and recycling of medical and industrial isotopes. Promotion is Canada's industry leader for value-driven engineered solutions in the isotope market.

Services/Products: Promotion Nuclear reliably delivers customer-centric customized turn-key solutions for isotope production, hot cell processing, handling, and medical isotope packaging. On time, on budget, every time!



RSCC Wire and Cable

www.r-scc.com

Pat Scanga
905-391-7766
pat.scanga@nesteam.ca

RSCC Wire & Cable LLC is a world leader in the design and manufacture of insulated high-performance control, power, instrumentation and specialty electrical cables.

Services/Products: Medium and low-voltage instrumentation, control and power cables, motor lead cables, fibreoptic cables, and much more.



South West Exposures

www.linkedin.com/in/swexposures/

Robert Kamen
416-930-0607
robert.kamen@swexposures.com

South West Exposures (SWE) designs and fabricates custom tungsten and lucite shielding solutions for nuclear medicine applications. Its value proposition is recognized for optimizing the safety profile of theranostic radiopharmaceuticals, by mitigating occupational radiation exposure and enhancing regulatory compliance, and from production to patient administration.

Services/Products: SWE offers both commercial and customizable shielding solutions, including Type A packages.



Stevcon Packaging & Logistics Ltd. (SP&L)

www.stevconpackaging.com

Stephen Warwick
416-505-3223
swarwick@stevconpackaging.com

Stevcon Packaging is a major packaging supplier to the nuclear industry, specializing in wood and steel containers.

Services/Products: Stevcon, in further support to the nuclear industry, will provides 'Made in Canada' solution for isotope packaging and being an integral part of the supply chain.



Sylvia Fedoruk Canadian Centre for Nuclear Innovation

Lidia Matei
306-229-3169
lidia.matei@fedorukcentre.ca

The Fedoruk Centre provides access to a state-of-the art facility designed for nuclear imaging, production, research and development of medical isotopes and radiopharmaceuticals. The infrastructure has a 24MeV cyclotron, radiochemistry laboratories and clean spaces for cGMP manufacturing, cell culture lab, housing for small animals, growth chambers for plants, PET/CT scanners and optical imagers.

Services/Products: The Fedoruk Centre offers cyclotron produced isotopes, radiopharmaceuticals and radiochemical compounds, expertise in cGMP manufacturing, and capabilities for nuclear imaging of living specimens.



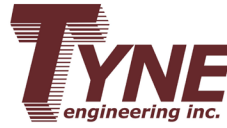
Tam Intl

www.tamintl.ca

Kevin Loyens
778-707-5573
kevin.loyens@tamintl.ca

TAM International is a logistics company specialized in the handling, packaging and worldwide transport of radioactive materials. TAM was founded in 2004 and supports the nuclear, mining, rare earth and isotope industries. It has offices across Canada, the U.S., the UK, Europe and India.

Services/Products: TAM provides air, ocean and land transport of isotopes across the world. This includes providing advice on packaging and the regulatory, safety and security requirements for these types of transports.



Tyne Engineering Inc.

www.tyne-engineering.com

Vince Robinson
289-288-0490
vince.r@tyne-engineering.com

Tyne Engineering designs and builds fixed-price turn-key systems from concept for commercial nuclear, fusion, and pharmaceutical industries. It has expertise in fully automated tritium and hydrogen systems, high vacuum, cryogenics, high pressure and temperature, and ultra-low leakage. It has three divisions: process systems, instrumentation and radiation monitoring, and commercial grade dedication.

Services/Products: Tyne solve challenges in-house, with skills in process and radiation modeling, stress analysis, shielding, tooling, glovebox, safety instruments, radiation monitors, and transport container design.



Trillium Flow Technologies

www.trilliumflow.com

Chris Lanteigne
905-625-7202
Chris.Lanteigne@trilliumflow.com

Trillium Flow Technologies manufactures process equipment for the nuclear industry. Our valves and pumps are used in plants globally and are instrumental in the generation of clean power and medical isotope production.

Services/Products: Its nuclear portfolio is built on highly engineered valves, actuators and pumps from world-class brands synonymous with variety, flexibility, reliability and trust.



Westinghouse Electric Company

www.westinghousenuclear.com/

Zaid Keldani
705-761-6608
zaid.keldani@westinghouse.com

Westinghouse is the world's leading nuclear energy company and supplier of products and innovative solutions to nuclear facilities and utilities globally. Westinghouse is developing technologies to advance the production of novel medical isotopes and establish new reliable supplies. Particularly, Westinghouse is developing novel technologies to produce Cobalt-60 in pressurized water reactors.

Services/Products: Westinghouse provides the isotopes market with design, manufacturing, and testing of tooling for source harvesting. It also offers licensing support and is exploring solutions for spent source disposal.

