canadian nuclear association

THE CANADIAN NUCLEAR FACTBOOK

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SUMMARY

MESSAGE FROM THE PRESIDENT

This book offers a snapshot of the role and achievements of nuclear power and technology in Canada and worldwide. I urge you to make good use of this reference when talking with colleagues, friends, family, and anyone else who wants to learn more about what our industry has to offer.

The nuclear industry plays a vital role in Canada, providing reliable, affordable, and low-carbon power for Canadian homes and businesses. As the world grapples with the question of how to ensure economies remain healthy and resilient in the face of geopolitical instability and the ever-present threat of climate change, nuclear power provides a solution to many of our shared challenges.

From our conventional reactors that have been supply stable, low-carbon power for generations, to newer designs including small modular reactors, Canada continues to be a world leader in nuclear. But it's not just about power - nuclear power and technology provide a host of other benefits, such as fighting cancer, ensuring food safety, powering spacecraft, and even supporting the nascent hydrogen economy.

We are proud of our accomplishments over the last 60 years, but we are always looking ahead. I invite you to read about what we have achieved, and what's coming in the next years and decades, in the Canadian Nuclear Factbook.

John Gorman
President and Chief Executive Officer
Canadian Nuclear Association

EXECUTIVE SUMMARY

The edition of the Canadian Nuclear Factbook is packed full of up to date information about nuclear in Canada and around the world. Some of the highlights are listed below.

- There are currently 422 operable nuclear reactors worldwide. Canada is home to 19 power reactors, which provide about 14% of the country's electricity.
- A total of 56 reactors are under construction worldwide, primarily in emerging economies such as China and India. About 100 reactors are on order or planned, while another 300 or more have been proposed.
- Nuclear power generation helps reduce global CO_2 emissions, which hit a record high of 36.6 billion tonnes in 2022.
- Nuclear in Canada generates more than $6 billion in revenues per year. It directly and indirectly supports a total of 76,000 Canadian jobs.
- Canada is a leader in the global supply of uranium. Most Canadian uranium is mined in northern Saskatchewan, which has the highest-grade ore deposits in the world.
- Canada pioneered one of the first nuclear power reactors, the CANDU®. There are currently 30 operable CANDU and CANDU-derived reactors worldwide.
- Nuclear technology is used extensively in medicine and industry. In Canada, over 1.3 million diagnostic scans and thousands of radiation therapy treatments are performed annually.
- Canada's nuclear industry is among the safest and most strictly regulated industries in the world.

® *REGISTERED TRADEMARK OF ATOMIC ENERGY OF CANADA, LTD. (AECL), USED UNDER EXCLUSIVE LICENCE BY CANDU ENERGY INC., A MEMBER OF THE SNC-LAVALIN GROUP*

HISTORY OF NUCLEAR IN CANADA

1900 - 1910

Ernest Rutherford is awarded the Nobel Prize in Chemistry for his work on radioactive decay, performed at McGill University in Montreal, QC.

1921 - 1930

Gilbert A. Labine discovers Canada's first uranium deposit in Great Bear Lake, NWT.

1931 - 1940

George C. Laurence designs one of the world's first nuclear reactors at the National Research Council (NRC) in Ottawa, ON.

1941 - 1950

The NRC begins building a nuclear research facility in Chalk River, ON.

The Zero Energy Experimental Pile (ZEEP) reactor makes Canada the second country to control a nuclear fission reaction.

The Atomic Energy Control Board (AECB) is established as Canada's federal nuclear regulator.

The National Research Experimental (NRX) reactor, then the most powerful reactor in the world, comes into operation at Chalk River.

1951 - 1960

Two separate teams led by Harold E. Johns and Roy Errington build the world's first two cobalt-60 radiation therapy units. The first external radiation cancer treatment is delivered in London, ON, and the second 11 days later in Saskatoon, SK.

Atomic Energy of Canada Limited (AECL) is created as a federal Crown corporation.

The NRX suffers an accident with reactor core damage —the first accident of this type. The reactor is decontaminated, rebuilt and restarted after 14 months.

Wilfrid B. Lewis initiates the development of the CANDU reactor in collaboration with AECL, Ontario Hydro and Canadian General Electric Company.

The National Research Universal (NRU) reactor comes into operation at Chalk River.

1961 - 1970

The Nuclear Power Demonstration (NPD) reactor, Canada's first electricity-producing reactor and the prototype for the CANDU design, comes online in Rolphton, ON, at a capacity of 20 MWe.

AECL develops the first commercial cobalt-60 sterilizer for food and medical supplies.

Douglas Point, Canada's first full-scale power reactor, comes online in Kincardine, ON, producing 220 MWe.

1971 - 1980

The first CANDU outside Canada comes online at Rajasthan-1 in India.

All four units at Pickering A come online at 2,060 MWe, making it the largest nuclear generating station in the world at the time.

AECL designs and builds the first SLOWPOKE research reactor.

1981 - 1990

Point Lepreau in New Brunswick and Gentilly-2 in Quebec come online at 635 MWe each.

Bertram N. Brockhouse is awarded the Nobel Prize in Physics for his neutron scattering research at Chalk River.

1991 - 2000

Two CANDU reactors are sold to China—the largest commercial contract between two countries at the time.

The Canadian Nuclear Safety Commission (CNSC) is formed under the new *Nuclear and Safety Control Act*, replacing the AECB as Canada's nuclear regulator.

2001 - 2010

The *Nuclear Fuel Waste Act* is passed, mandating the creation of the Nuclear Waste Management Organization (NWMO). In 2007, the federal government approved the NWMO's Adaptive Phased Management approach for the long-term storage of used nuclear fuel.

The assets of AECL's CANDU Reactor Division are acquired by Candu Energy Inc., a wholly owned subsidiary of SNC-Lavalin. AECL remains a federal Crown corporation.

2011 - 2020

Two units at Bruce A come back online after being refurbished, making the Bruce Nuclear Generating Station the largest operating nuclear generating station in the world.

Arthur B. McDonald is awarded the Nobel Prize in Physics for demonstrating, at the Sudbury Neutrino Observatory in Ontario, that neutrinos have mass.

AECL establishes a government-owned, contractor-operated arrangement whereby its sites and facilities are managed and operated by Canadian Nuclear Laboratories.

Ontario begins the process of refurbishing 10 of its 18 nuclear power reactors—currently the largest clean energy project in North America.

The NRU is permanently shut down after more than 60 years of operation.

The Prime Minister of Canada announces a new Institute for Advanced Medical Isotopes in the TRIUMF facility at the University of British Columbia.

A diverse group of federal, provincial, industry and research stakeholders collaborate to produce *A Call to Action: A Canadian Roadmap for Small Modular Reactors*.

The premiers of Saskatchewan, Ontario, and New Brunswick sign a memorandum of understanding to develop small modular reactors, to help fight climate change. In 2021, Alberta signs the memorandum as well.

2021 - PRESENT

Natural Resources Canada coordinates creation and launch of the national Small Modular Reactor Action Plan.

Ontario Power Generation (OPG) is with GE Hitachi Nuclear Energy to deploy Small Modular Reactor at the Darlington new nuclear site, the only site in Canada currently licensed for a new nuclear build.

Utility SaskPower selected GE Hitachi Nuclear Energy's small modular reactor for potential deployment in the province in the mid-2030s. The selection follows an independent and comprehensive process that also included close collaboration with OPG as potential for a pan-Canadian, fleet-based deployment of nuclear power.

Ontario decided to extend the life of the Pickering Nuclear Generating Station until 2026 and is looking to see if it can refurbish the plant to run for another 30 years to fill an expected energy gap.

The International Atomic Energy (IAEA) attended the 27th United Nations Climate Change Conferences in Sharm El Sheik, Egypt, more commonly referred to as COP27, and organizes several events to highlight how nuclear technology and applications contribute to tackling climate change.

The 2022 Fall Economic Statement included the Clean Technology Investment Tax Credit (Clean Tech ITC) which gives refundable tax credit equal to 30 percent for small modular nuclear reactors.

NUCLEAR POWER GLOBALLY AND IN CANADA

NUCLEAR POWER GLOBALLY

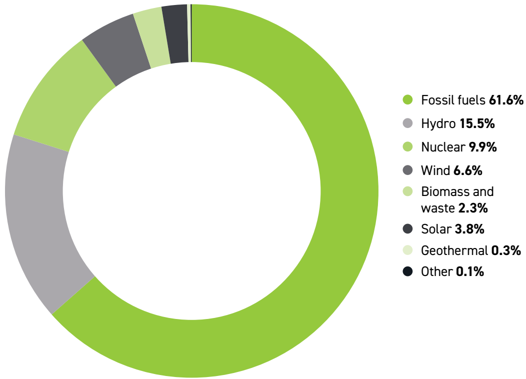
Nuclear generated 9.9% of global electricity in 2021.

After hydroelectricity, it is the largest source of low-carbon energy worldwide.

Fossil fuels were the most widely used electricity source by far, at 61.6%. Coal represents about two-thirds of this, and natural gas represents about one-third.

The most common non-hydro renewable sources (wind, solar, geothermal, biomass and tidal), generated 13.1% combined.

GLOBAL SOURCES OF ELECTRICITY IN 2021



SOURCE: U.S. Energy Information Administration. "International Energy Statistics." 2023. https://www.eia.gov/international/data/world

NUCLEAR REACTORS GLOBALLY

Currently, there are 422 operable power reactors worldwide, with a net generating capacity of approximately 378 gigawatts (GW).

- This includes 37 Japanese reactors that were taken offline shortly after the 2011 Fukushima accident. As of February 2021, nine have been restarted and 16 more are in the approval process for restarting.
- Germany decided to extend the operation of their 3 remaining nuclear plants to fend off energy shortages brought by Russia's invasion of Ukraine in 2022.
  such as China and India.

A total of **56** reactors are under construction worldwide, primarily in emerging economies

There are over 100 reactors on order or planned, while 300+ more have been proposed.

442
OPERABLE POWER REACTORS

56
REACTORS UNDER CONSTRUCTION

100+
REACTORS ON ORDER OR PLANNED

300+
PROPOSED REACTORS

SOURCE: IAEA Power Reactor Information System. "Operational & Long Term Shutdown Reactors." 2023. https://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx.
World Nuclear Association. "Plans for New Reactors Worldwide." 2023. https://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx.

CURRENT NUCLEAR POWER REACTORS

COUNTRY	UNITS	NET CAPACITY (MWE)	ELECTRICITY PRODUCTION SHARE (%)
Argentina	3	1,641	7.2
Armenia	1	448	25.3
Belarus	1	1,110	14.1
Belgium	6	4,936	50.8
Brazil	2	1,884	2.4
Bulgaria	2	2,006	34.6
Canada	19	13,624	14.3
China	55	52,170	5.0
Czech Republic	6	3,934	36.6
Finland	5	4,394	32.8
France	56	61,730	69.0
Germany	3	4,055	11.9
Hungary	4	1,902	46.8
India	22	6,795	3.2
Iran	1	915	0
Japan	17	16,321	7.2
Mexico	2	1,552	5.3

COUNTRY	UNITS	NET CAPACITY (MWE)	ELECTRICITY PRODUCTION SHARE (%)
Netherlands	1	482	3.1
Pakistan	6	3,256	10.6
Romania	2	1,300	18.5
Russia	37	27,727	20.0
Slovakia	4	1,868	52.3
Slovenia	1	688	37.8
South Africa	2	1,854	6.0
South Korea	25	24,415	28.0
Spain	7	7,123	20.8
Sweden	6	6,935	30.8
Switzerland	4	2,973	28.8
Ukraine	15	13,107	55.0
United Arab Emirates	3	4,107	1.3
United Kingdom	9	5,883	14.8
United States	92	94,718	19.6
Total	**422**	**378,754**	
THIS INFORMATION IS ALSO PART OF THE TOTALS:			
Taiwan	3	2,859	10.8

SOURCE: IAEA Power Reactor Information System. "Operational & Long Term Shutdown Reactors." 2023. https://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx.

NUCLEAR POWER IN CANADA

There are 19 operable power reactors at four nuclear generating stations in Canada.

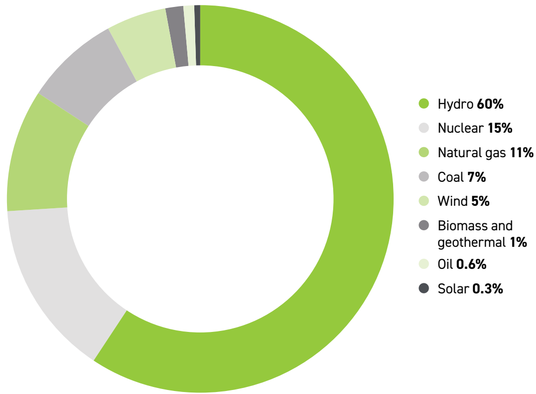
Nuclear power provided approximately 15% of Canada's electricity in 2019.

Hydro power is the largest source of electricity in Canada, generating approximately 60% of the electricity in 2019.

While coal was phased out in Ontario in 2014, it continues to be widely used elsewhere in the country.

Non-hydro renewable sources provided approximately 6.9% of Canada's electricity in 2019.

CANADIAN SOURCES OF ELECTRICITY IN 2019



CANADA'S NUCLEAR POWER REACTORS

FACILITY	STATUS	NET CAPACITY (MWE)	START YEAR
Bruce A: Unit 1	Operable	760	1977
Bruce A: Unit 2	Operable	760	1976
Bruce A: Unit 3	Operable	750	1977
Bruce A: Unit 4	Operable	750	1978
Bruce B: Unit 5	Operable	817	1984
Bruce B: Unit 6	Operable	817	1984
Bruce B: Unit 7	Operable	817	1986
Bruce B: Unit 8	Operable	817	1987
Darlington: Unit 1	Operable	878	1990
Darlington: Unit 2	Operable	878	1990
Darlington: Unit 3	Operable	878	1992
Darlington: Unit 4	Operable	878	1993
Douglas Point*	Shut down	206	1967

FACILITY	STATUS	NET CAPACITY (MWE)	START YEAR
Gentilly-1*	Shut down	250	1971
Gentilly-2	Shut down	635	1983
Pickering A: Unit 1	Operable	515	1971
Pickering A: Unit 2	Shut down	515	1971
Pickering A: Unit 3	Shut down	515	1972
Pickering A: Unit 4	Operable	515	1973
Pickering B: Unit 5	Operable	516	1982
Pickering B: Unit 6	Operable	516	1983
Pickering B: Unit 7	Operable	516	1984
Pickering B: Unit 8	Operable	516	1986
Point Lepreau	Operable	660	1982
Rolphton Nuclear Power Demonstration*	Shut down	22	1962

***PROTOTYPE**

SOURCE: IAEA Power Reactor Information System. "Canada." 2023. https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CA

ELECTRICITY SOURCES BY PROVINCE

Electricity sources vary significantly by province.

In 2019, nuclear power provided approximately 59% of Ontario's electricity and 38% of New Brunswick's electricity.

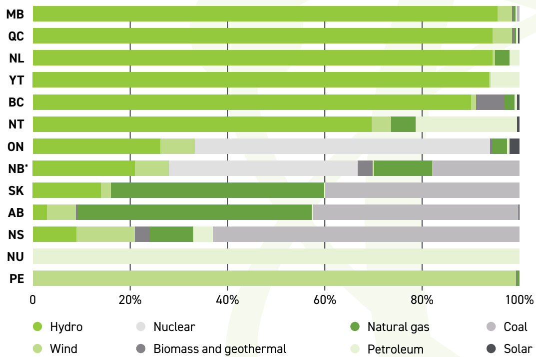
Hydro power is the dominant source of electricity in British Columbia, Manitoba, Quebec, Newfoundland, the Northwest Territories, and Yukon.

Natural gas makes up 54% of power generation in Alberta, followed closely by coal. In Saskatchewan, electricity is produced from fossil fuels – approximately 41% from coal and 40% from natural gas.

Fossil fuels still provide most of the power in Nova Scotia and Nunavut.

While 99% of power generation in Prince Edward Island is from wind farms, the province still imports about 60% of its electricity from New Brunswick.

SOURCES OF ELECTRICITY BY PROVINCE IN 2019



*In New Brunswick and Nova Scotia, hydro includes wave and tidal power.

SOURCE: Canada Energy Regulator. "Provincial & Territorial Energy Profiles." 2023. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/index.html

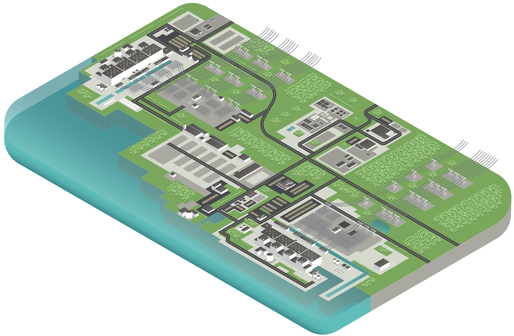
BRUCE NUCLEAR GENERATING STATION

Bruce Nuclear Generating Station (NGS) has eight reactors, making it the largest operating nuclear power facility in the world. It is located on the shore of Lake Huron, 190 km from downtown Toronto, Ontario, and first delivered power to the grid in 1976.

Operating at 6,400 MWe from eight reactors, Bruce NGS generated 43.23 billion kWh in 2020—enough electricity to power more than five million Ontario households.

(An average Ontario household consumes about 8,493 kWh per year.)

In 2016, Bruce Power began the mid-life refurbishment of Units 3 to 8, replacing major components so that they can continue operating for decades to come. The first of these (Unit 6) was taken offline for refurbishment in January 2020.



6,400 MWE OUTPUT

FIRST POWER TO GRID IN 1976

CAPABLE OF POWERING 5.1 MILLION ONTARIO HOMES

CURRENTLY THE LARGEST OPERATING NGS IN THE WORLD!

SOURCES: Ontario Energy Board. “2019 Yearbook of Electricity Distributors.” https://www.oeb.ca/oeb/_Documents/RRR/2019_Yearbook_of_Electricity_Distributors.pdf?v=20201116.

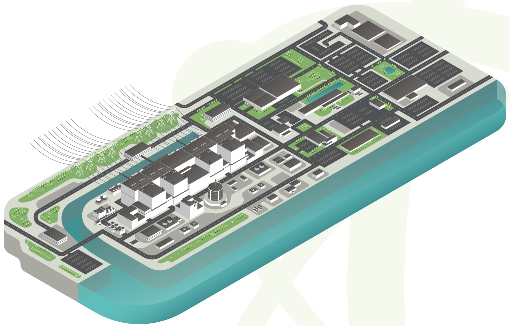
Bruce Power. “The Ontario Energy Report.” 2020. https://www.brucepower.com/wp-content/uploads/2020/01/2020_OntarioEnergyReport-1.pdf.

DARLINGTON NUCLEAR GENERATING STATION

Darlington NGS is Canada's second-largest nuclear facility. It is located on the shore of Lake Ontario, 70 km from downtown Toronto, Ontario.

Operating at 3,512 MWe from four reactors, Darlington NGS generates enough electricity to power more than 20% of Ontario's electricity needs, or 2 million Ontario households.

Unit 2 was shut down in October 2016 for its mid-life refurbishment. After completion of the refurbishment in April 2020—ahead of schedule and under budget—Unit 2 was returned to service in June 2020. Refurbishment of Unit 3 is now underway, and completion is expected in 2024. The Unit 1 refurbishment execution began in February 2022 and is currently 25 per cent complete. Unit 4 planning is progressing well, incorporating lessons learned from work done on all 3 refurbishments.



3,512
MWE OUTPUT

CAPABLE OF POWERING 2 MILLION ONTARIO HOMES

FIRST POWER TO GRID IN 1990

SOURCE: Ontario Power Generation. "Darlington Refurbishment." 2023. https://www.opg.com/strengthening-the-economy/our-projects/darlington-refurbishment/.

PICKERING NUCLEAR GENERATING STATION

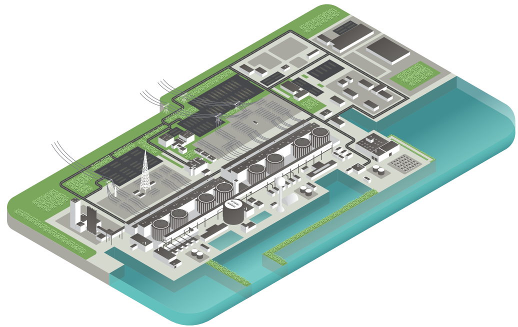
When Unit 4 was completed in 1973, Pickering A became the world's largest nuclear generating station at the time. Pickering A and B are located 30 km from downtown Toronto, Ontario.

With a combined six operating reactors at Pickering A and B producing 3,100 MWe, Pickering NGS accounts for approximately 14% of Ontario's energy needs.

Pickering NGS had eight reactors in total until Units 2 and 3 were shut down in 1997.

The remaining reactors are scheduled to run until 2024, at which point they will be decommissioned.

In 2022, the Ontario government has asked OPG to conduct a feasibility assessment on the potential for refurbishing Units 5 – 8. OPG will conduct a comprehensive technical examination and hope to submit a final recommendation to the Province by the end of 2023.



3,100
MWE OUTPUT

ACCOUNTS FOR APPROXIMATELY 14% OF ONTARIO'S ENERGY NEEDS

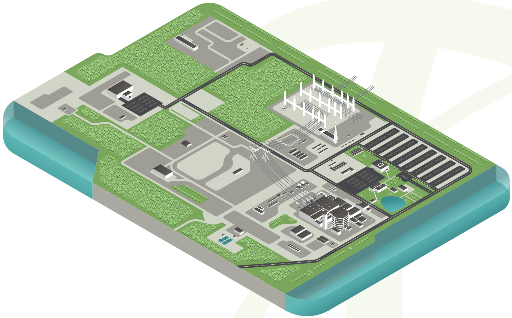
FIRST POWER TO GRID IN 1971

POINT LEPREAU NUCLEAR GENERATING STATION

Point Lepreau NGS is located in New Brunswick, approximately 30 km southwest of Saint John, and was the first CANDU 6 unit to generate electricity commercially.

Point Lepreau underwent refurbishment to extend its operational lifespan and returned to service in November 2012. It currently provides approximately 38% of New Brunswick's electricity.

Point Lepreau operates at 660 MWe, producing 5.8 billion kWh in 2019, or enough to power 333,000 New Brunswick households. (An average New Brunswick household consumes about 17,000 kWh per year.)



660
MWE OUTPUT

CAPABLE OF POWERING 333,000 NEW BRUNSWICK HOMES

FIRST POWER TO GRID IN 1983

SOURCE: Canada Energy Regulator. "Provincial and Territorial Energy Profiles—New Brunswick." 2023. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-new-brunswick.html

CANADA'S NUCLEAR REFURBISHMENT PROJECTS

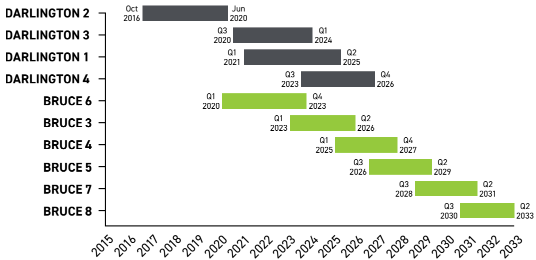
The life of a nuclear reactor can be extended for several decades through refurbishment, a process of modernizing and enhancing major equipment and systems to support long-term operation.

Canada has begun the process of refurbishing 10 of its 19 nuclear reactors to extend their lives for another 30 years. The refurbishment projects are expected to last 15 years and create thousands of jobs.

Point Lepreau and Bruce Units 1 and 2 were already refurbished. All three reactors returned to service in 2012.

According to a study by the Ontario Chamber of Commerce, the Bruce Power's Life-Extension Program will have a national economic impact is estimated to be between CAD8.1 billion and CAD11.6 billion.

NUCLEAR REFURBISHMENT SEQUENCE



SOURCES: Ontario Power Generation. "Darlington Refurbishment." 2023. https://www.opg.com/strengthening-the-economy/our-projects/darlington-refurbishment/.
Bruce Power. "Life-Extension Program & MCR Project." 2023. https://www.brucepower.com/life-extension-program-mcr-project/.
The Ontario Chamber of Commerce. "Bruce Power Major Component Replacement Project: Economic Impact Analysis." 2019, pp. 3.

THE ENVIRONMENT AND THE ECONOMY

ENERGY AND THE ENVIRONMENT

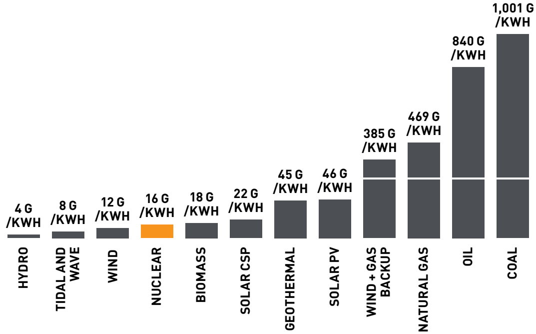
All forms of electricity production generate some level of CO_2 and other greenhouse gases (GHGs), even if they do not burn fossil fuels. The construction of the plant or equipment, for example, requires cement production and vehicle use, each having its own carbon footprint.

When considering the entire power generation lifecycle, including construction, mining, operation and decommissioning, nuclear comes out as one of the cleanest technologies available.

Hydro also is a low-carbon source of electricity, but it is only feasible in locations with access to large quantities of flowing water.

Solar and wind are low-carbon sources of electricity as well, but to exclusively power a grid they would require backup sources most of the time. Backup most often comes from burning natural gas, which increases CO_2 emissions greatly.

LIFECYCLE CO_2 EMISSIONS BY ENERGY SOURCE



SOURCE: Intergovernmental Panel on Climate Change. "IPCC Working Group III – Mitigation of Climate Change, Annex III: Technology-specific Cost and Performance Parameters - Table A.III.2 (Emissions of selected electricity supply technologies (gCO $_2$eq/kWh))" 2014, p. 1335. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7.

GLOBAL CO_2 EMISSIONS OVER TIME

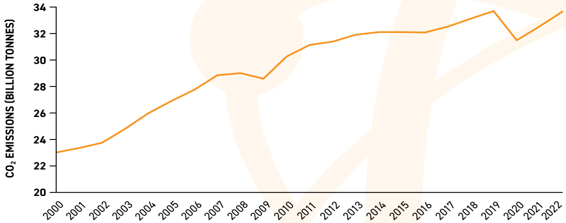
Global energy-related CO_2 emissions reached a record high of 36.6 billion tonnes in 2022. The increase in fossil emissions in 2022 has been primarily driven by a strong increase in oil emissions as global travel continues to recover from the Covid-19 pandemic.

Fossil fuel use is the primary source of CO_2 emissions.

If we replaced all the world's coal and natural gas plants with low-carbon nuclear, we would reduce global CO_2 emissions by nearly 13 billion tonnes annually.

Today, by displacing the use of coal and natural gas, nuclear power helps avoid about 2.2 billion tonnes of CO_2 emissions annually. That's the same as taking about a third of all the world's cars off the road!

GLOBAL CO_2 EMISSIONS SINCE 2000



SOURCES: World Nuclear Association. "How can nuclear combat climate change?" 2023. https://www.world-nuclear.org/nuclear-essentials/how-can-nuclear-combat-climate-change.aspx.
United States Environmental Protection Agency. "Greenhouse Gas Emissions from a Typical Passenger Vehicle." 2023. https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle.
World Economic Forum. "Analysis: Global CO2 emissions from fossil fuels hits record high in 2022." 2023. https://www.weforum.org/agenda/2022/11/global-co2-emissions-fossil-fuels-hit-record-2022/

CANADA'S CLIMATE TARGETS

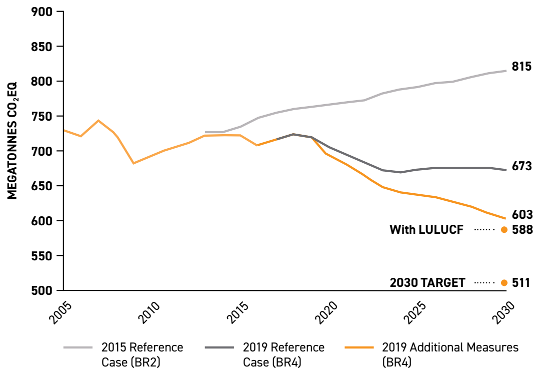
Climate change is one of the greatest threats of our time.

Under the 2015 Paris Agreement, Canada, along with 194 other countries, agreed to transition to a low-carbon economy and meet country-specific GHG reduction targets.

With current measures, Canada is not likely to meet its 2030 targets.

To drastically reduce emissions, Canada must embrace all available low-carbon energy sources, including nuclear.

CANADA'S GHG EMISSIONS PROJECTIONS



SOURCE: Environment and Climate Change Canada. "Greenhouse gas and air pollutant emissions projections: 2019." https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/projections/2019.html

NUCLEAR AND THE UN'S SUSTAINABLE DEVELOPMENT GOALS

Canada's nuclear industry contributes directly to nine of the United Nation's 17 Sustainable Development Goals (SDGs) and indirectly to the other eight, which were designed to ensure the prosperity of developed countries and improve living conditions in developing countries by 2030.

NUCLEAR CONTRIBUTES DIRECTLY TO:

2: ZERO HUNGER

Nuclear technology helps protect plants from pests and improve crop resilience to disease and climate change.

3: GOOD HEALTH AND WELL-BEING

Nuclear technology is used to diagnose and treat diseases, including cancer, and to eliminate pathogens from food products and medical supplies.

6: CLEAN WATER AND SANITATION

Nuclear technology can help clean up wastewater contaminants, making the water safe for re-use.

7: AFFORDABLE AND CLEAN ENERGY

Nuclear is one of the cheapest forms of energy and emits zero GHGs during generation.

9: INDUSTRY, INNOVATION AND INFRASTRUCTURE

The nuclear industry is pursuing innovative research into future energy options and technology improvements.

13: CLIMATE ACTION

Nuclear energy emits zero GHGs during generation, reducing the impact of human activity on the climate.

14: LIFE BELOW WATER

Nuclear technology can provide a window into ocean health so that oceans can be better understood and protected. For example, nuclear technology is used to analyze seawater to trace pollutants to their sources and to detect algal blooms.

15: LIFE ON LAND

Nuclear technology is used for environmental risk assessments to protect forests and to reverse biodiversity loss.

17: PARTNERSHIPS FOR THE GOALS

The nuclear industry has a long history of working with stakeholders to find solutions to global problems.

NUCLEAR'S LAND FOOTPRINT

Nuclear is the most land-efficient means of clean electricity production, requiring only 103 acres per million-megawatt hours.

Other low-carbon options, such as solar, and wind, require far more land at 3200 acres per million-megawatt hours and 17800 acres per million-megawatt hours per year, respectively.

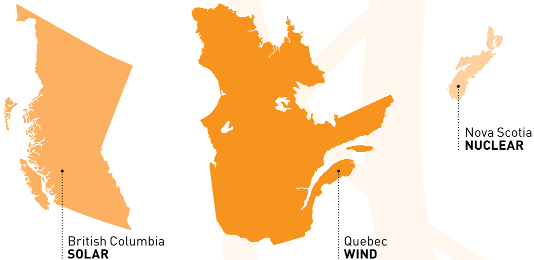
To produce 100% of global electricity with only one source, nuclear would require an area the size of Nova Scotia. Solar would occupy British Columbia and wind would need almost all of Quebec.

As a result of its small land footprint, nuclear has a very minimal impact on natural habitats.

The impact of wind turbines on birds and bats has been well documented, as has the impact of hydro dams on aquatic ecosystems.

Fossil fuel extraction has serious impacts on forests, grasslands and water supply.

LAND USE REQUIRED TO SUPPLY GLOBAL ELECTRICITY



SOURCE: Nuclear Energy Institute. "Nuclear Needs Small Amounts of Land to Deliver Big Amounts of Electricity" 2023. https://www.nei.org/news/2022/nuclear-brings-more-electricity-with-less-land.

McDonald, Robert, et al. "Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America." PLoS ONE. 2009. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0006802.

NUCLEAR AND THE CANADIAN ECONOMY

Nuclear technology can be an integral part of any advanced economy. It supports medicine, materials science, advanced manufacturing, food safety and energy production. In addition, nuclear energy has a vital role in developing Canada's role in being a leader in clean hydrogen production.

The nuclear industry directly and indirectly supports a total of 76,000 Canadian jobs, with a total impact on the Canadian GDP of $17 billion per year.

Nearly 200 Canadian companies supply products or services to the nuclear industry. While the bulk of these jobs are related to power generation, mining uranium is also a major source of employment—and the medical isotope industry alone creates 8,500 jobs. In addition, nuclear energy has a vital role in developing Canada's role in being a leader in clean hydrogen production.

Jobs in nuclear generally require advanced skills and are well paid.

The economic benefits of the sector are growing as major work is underway to extend the existing fleet and more projects are planned, including:

- Refurbishment of Ontario's nuclear fleet, extending the lives of these reactors.
- An SMR project at Darlington station in Ontario to be in service by 2029, with plans for 3 more.
- A $1.2-billion investment to revitalize AECL's Chalk River Laboratories.
- Commitments from four provinces to explore and promote development of small modular reactors.
- Plans from four provinces to explore and promote development of small modular reactors.
- A new Institute for Advanced Medical Isotopes at the University of British Columbia.

The nuclear industry in Canada has revenues of over $6 billion annually.

SOURCE: MZ Consulting Inc. "Benefits of Nuclear Energy for Canadians." Canadian Nuclear Association. 2019. https://cna.ca/wp-content/uploads/2019/11/MZ-Consulting-Benefits-of-Nuclear-Energy-for-Canadians.pdf.

URANIUM MINE PRODUCTION

Canada is the second largest uranium producer in the world, with Cameco Corporation and Orano Canada as its two primary uranium mining companies.

Canada exports 85% of the uranium it mines. All of Canada's uranium exports are for peaceful applications.

Uranium exports add more than $1 billion to the Canadian economy annually.

Uranium mining is one of the leading industrial employers of Indigenous people in Saskatchewan.

DID YOU KNOW?

CANADA HAS 514,000 TONNES OF KNOWN URANIUM RESERVES—THE FOURTH LARGEST IN THE WORLD!

GLOBAL URANIUM MINE PRODUCTION IN 2021

COUNTRY	TONNES U	GLOBAL SHARE (%)
Kazakhstan	21,819	45
Canada	4,693	10
Australia	4,192	9
Namibia	5,753	12
Uzbekistan	3,500	7
Niger	2,248	5
Russia	2,635	5
China	1,885	4
Ukraine	455	1
South Africa	385	1
India	615	1

SOURCES: Natural Resources Canada. "About Uranium." 2023. https://www.nrcan.gc.ca/energy/uranium-nuclear/7695.
Natural Resources Canada. "The Canadian Nuclear Industry and its Economic Contributions." 2023. https://www.nrcan.gc.ca/energy/uranium-nuclear/7715.
World Nuclear Association. "World Uranium Mining Production." 2023. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx.

COST OF NUCLEAR POWER

Nuclear remains one of the most affordable electricity sources worldwide.

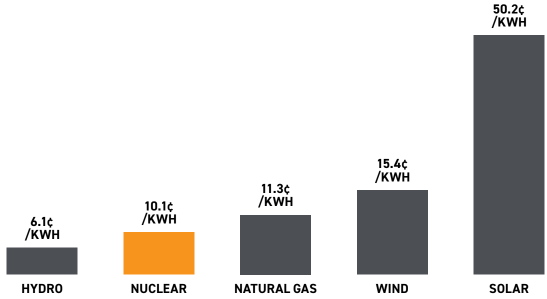
While nuclear generating stations require high upfront capital investment, their long life and low costs for fuel, operations and maintenance lead to low power costs in the long run.

In Ontario, only hydro has a lower cost per kilowatt-hour than nuclear. Gas is about a third more expensive than nuclear, wind is about two thirds more expensive, and solar is more than five times as expensive.

DID YOU KNOW?

MORE THAN HALF THE COST OF NUCLEAR IS ATTRIBUTED TO FACILITY CONSTRUCTION – AN AREA THAT MODULARIZATION COULD GREATLY IMPROVE. ONCE BUILT, NUCLEAR HAS VERY LOW FUEL AND MAINTENANCE COSTS, PROVIDING STABLE ELECTRICITY PRICES OVER THE PLANT'S LIFETIME OF 60+ YEARS.

COST OF ENERGY BY SOURCE IN ONTARIO IN 2022



SOURCE: Ontario Energy Board. "Regulated Price Plan Price Report from November 1, 2022 to October 31, 2023." 2023, p. 19. https://www.oeb.ca/sites/default/files/rpp-price-report-20191022.pdf.

URANIUM AND NUCLEAR REACTORS

URANIUM

Uranium is a heavy metal and one of many naturally occurring radioactive elements. It exists in most rocks and soils at approximately two to four parts per million—about the same concentration as tin.

Like other elements, uranium occurs in several different forms, known as isotopes.

The most common isotope of uranium is U-238 (99.28%), followed by U-235 (0.71%). The number following the "U" indicates the atomic weight of the isotope.

U-235 is the primary isotope of uranium that is used to generate electricity because it is fissile (i.e., can be easily split or "fissioned"). Fission releases 100 million times more energy per atom than the chemical energy that's released in a combustion reaction.

DID YOU KNOW?

CANDU REACTORS USE U-235 IN ITS NATURAL CONCENTRATION (0.71%), WHEREAS OTHER REACTOR DESIGNS USE FUEL ENRICHED TO 3% U-235 OR HIGHER.

CONVERTING URANIUM ORE INTO CANDU REACTOR FUEL

MINING

Uranium ore is extracted from the ground in one of three ways: open-pit mining, underground mining or in-situ recovery.

MILLING

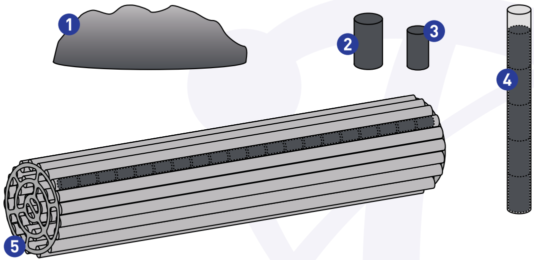
The ore is crushed in a mill and ground to a fine slurry. The slurry is leached in acid to separate the uranium from the minerals, which is then purified to produce uranium oxide powder.

REFINING

A series of chemical processes separate the uranium oxide from impurities, producing high-purity uranium trioxide.

CONVERSION

Uranium trioxide is converted to uranium dioxide.



FUEL MANUFACTURING

Uranium dioxide powder 1 is pressed into small cylindrical pellets 2, which are baked at high temperatures and finished to precise dimensions 3. Pellets are loaded into fuel tubes 4, which are then assembled into reactor-ready bundles 5.

URANIUM MINING METHODS

There are three ways of mining uranium:

Open-pit mining is used when uranium deposits are located near the surface. It involves removing a layer of soil and waste rock, and then excavating a pit to access the ore. The walls of the pit are mined in a series of benches to prevent them from collapsing.

Underground mining is the preferred method when deposits are found deep underground. It involves digging a vertical shaft to the depth of the ore, and then cutting a number of tunnels to access the ore directly.

In-situ recovery (or in-situ leaching) is the process of dissolving the uranium ore by pumping mining solutions underground, bringing them back to the surface, and extracting the dissolved uranium. Though not currently used in Canada, in-situ recovery is the fastest-growing mining method.

IMAGE: CAMECO

CANADA'S URANIUM INDUSTRY

Most Canadian uranium is mined and milled in northern Saskatchewan, in the Athabasca Basin region.

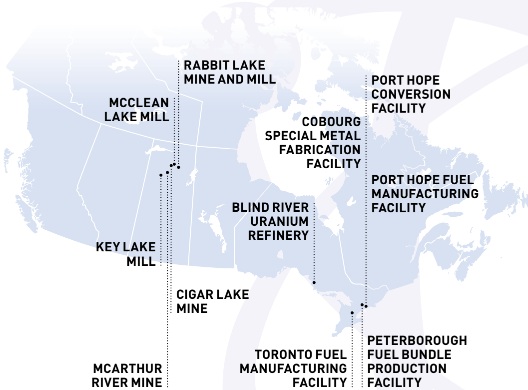
Canada has the world's highest-grade uranium deposits, with grades more than 100 times the global average.

Blind River, Ontario, is home to Canada's only uranium refining facility. Owned and operated by Cameco, it is the largest such facility in the world.

Port Hope, Ontario, is home to Canada's only uranium conversion facility, also owned and operated by Cameco.

Plants that process natural uranium powder and assemble CANDU fuel bundles are located in Port Hope (Cameco), as well as in Toronto and Peterborough (BWXT Nuclear Energy Canada), Ontario.

MAP OF CANADIAN URANIUM FACILITIES



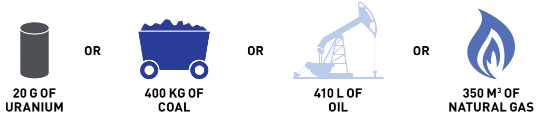
THE POWER OF URANIUM

Nuclear fission is very energy-dense, so a nuclear reactor requires very little fuel.

Uranium pellets are approximately 20 g each, and fewer than 10 are needed to power the average Canadian household for a year.

Providing the same amount of electricity as one 20-g uranium pellet would require 400 kg of coal, 410 L of oil or 350 m^3 of natural gas.

FUEL REQUIRED TO PRODUCE THE SAME AMOUNT OF ELECTRICITY



CANDU FUEL BUNDLE

IMAGE: NUCLEAR WASTE MANAGEMENT ORGANIZATION

HOW FISSION WORKS

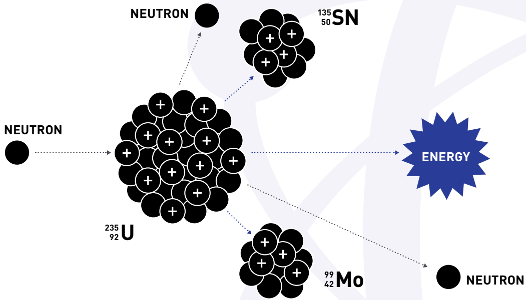
Uranium, in both of its main isotopes, U-235 and U-238, emits very little radiation before it is used in the reactor—so little that unused fuel bundles are safe to handle.

When a neutron collides with a U-235 atom, however, the atom undergoes fission. It splits into several pieces, including two or three extra neutrons, and releases heat that can be converted into electricity.

These extra neutrons then collide with other nearby U-235 atoms, prompting more fission and allowing the effect to continue. Nuclear reactors control this chain reaction to the desired stable state.

This process also produces other smaller isotopes, such as iodine-131, cesium-137 and molybdenum-99, which are useful in medicine and industry.

NUCLEAR FISSION



NUCLEAR REACTORS

A nuclear reactor is a highly sophisticated steam engine that turns an electrical generator. The heat used to generate the steam comes from the energy produced by the fission reaction.

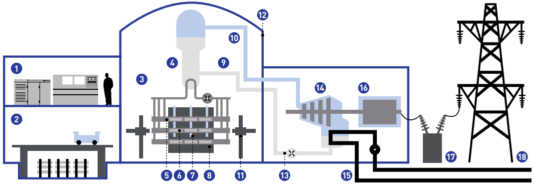
The basic parts of a nuclear reactor are the uranium fuel, the moderator and the coolant.

Depending on the reactor type, the uranium may be natural, of which 0.71% is U-235, or enriched so that the U-235 makes up 3% or more of the total.

The moderator is a light material, such as water, that slows down the neutrons without capturing them. By slowing down the fast neutrons created during fission, the moderator allows further fission.

The coolant is a fluid circulating through the reactor core that is used to absorb and transfer the heat produced by nuclear fission. It also maintains the temperature of the fuel within acceptable limits.

CANDU REACTOR SCHEMATIC



1. Control room
2. Used fuel management
3. Reactor core
4. Steam generator (boiler)
5. Coolant (heavy water)
6. Fuel (uranium)
7. Control rods
8. Moderator (heavy water)
9. Water
10. Steam
11. Fueling machine
12. Shielding
13. Condenser
14. Steam turbine
15. Condenser cooling water
16. Electrical generator
17. Transformer
18. Electrical grid

Nuclear reactors use the energy produced by a chain reaction in nuclear fuel to generate electricity. In a CANDU reactor, the steps for generating electricity are as follows:

1. Operators load natural uranium into a reactor core. When there is enough fuel concentrated in the core, neutrons from the uranium start a chain reaction.
2. The neutrons in the chain reaction travel at many speeds, but the slow ones are the best at splitting uranium atoms. The core sits in a moderator (heavy water, in the case of CANDU) that slows the neutrons down.
3. Reactor operators in the control room keep the reaction controlled and steady, so that the reactor generates heat without getting too hot. They move control rods in and out of the reactor core. The rods are made of materials that absorb neutrons and can slow or stop fission as needed.
4. The reactor could get very hot. So, a coolant (also heavy water for CANDU reactors) circulates through the reactor core to cool it down.
5. The coolant also gets hot, but this is useful heat. Despite its name, the coolant boils into high-pressured steam. The pressure pushes the steam to turn turbines. The coolant is then circulated back into the reactor to be re-used.
6. The energy of the spinning turbines drives an electrical generator, which converts the movement into electricity – very much the way a wind turbine works. That electricity powers the electrical grid.

CANDU REACTORS

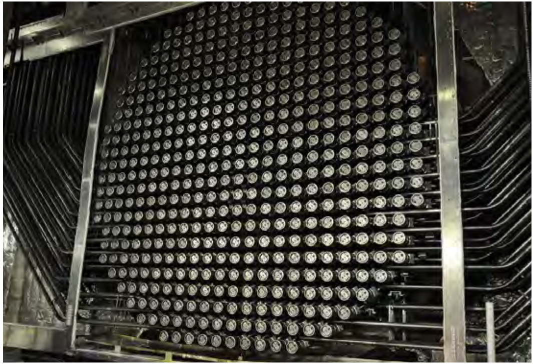
CANDU stands for CANada Deuterium Uranium, because it was invented in Canada, uses deuterium oxide (also known as heavy water) as a moderator and coolant, and uses uranium as a fuel.

CANDU reactors are unique in that they use natural, unenriched uranium as a fuel. With some modification, they can also use thorium, recycled uranium and mixed fuels.

CANDU reactors can be refuelled while operating at full power, while most other reactors are designed to be shut down for refuelling.

CANDU reactors are exceptionally safe. The safety systems are independent from the rest of the plant, and each key safety component has three backups. This multiplication of safety measures is often referred to as "redundancy" or "defence in depth." Not only does this increase the overall safety of the system, but it also makes it possible to test the safety systems while the reactor is operating at full power.

CANDU REACTOR FACE AT BRUCE A



CANDU REACTORS GLOBALLY

Canada has exported CANDU reactors to Argentina, China, India, Pakistan, Romania and South Korea. In total, there are 34 CANDU reactors globally, 27 of which are currently operable.

There are also 16 reactors built in India that are based on the CANDU design but are not technically CANDUs.

CERNAVODA (ROMANIA)

QINSHAN (CHINA)

EMBALSE (ARGENTINA)

WOLSONG (SOUTH KOREA)

IMAGES: SNC-LAVALIN

CANDU AND CANDU-DERIVED REACTORS GLOBALLY

FACILITY	UNITS	STATUS	REFERENCE UNIT POWER (MW)
Bruce Power	8 CANDU reactors	Operable	6, 358
Darlington	4 CANDU reactors	Operable	3,512
Pickering	6 CANDU reactors	Operable	3,094
	2 CANDU reactors	Shut down	1,030
Point Lepreau	1 CANDU reactor	Operable	660
Gentilly-2	1 CANDU reactor	Shut down	635
Cernavoda (Romania)	2 CANDU reactors	Operable	1,300
Embalse (Argentina)	1 CANDU reactor	Operable	608
Karachi (Pakistan)	1 CANDU reactor	Shut down	90
Kaiga (India)	4 CANDU-derived reactors	Operable	808

FACILITY	UNITS	STATUS	REFERENCE UNIT POWER (MW)
Kakrapar (India)	3 CANDU-derived reactors	Operable	1,034
Madras (India)	2 CANDU-derived reactors	Operable	410
Narora (India)	2 CANDU-derived reactors	Operable	404
Rajasthan (India)	2 CANDU reactors	Operable	277
	4 CANDU-derived reactors	Operable	808
Tarapur (India)	2 CANDU-derived reactors	Operable	980
Qinshan (China)	2 CANDU reactors	Operable	1,354
Wolsong (South Korea)	3 CANDU reactors	Operable	1,823
	1 CANDU reactor	Shut down	661

SOURCE: IAEA Power Reactor Information System. "Country Statistics." 2023. https://www.iaea.org/PRIS/CountryStatistics/CountryStatisticsLandingPage.aspx.

POWER REACTOR DESIGNS GLOBALLY

CANDU reactors are a type of pressurized heavy water reactor (PHWR). They are one of several power reactor designs currently used worldwide.

Different designs use different concentrations of uranium for fuel, different moderators and different coolants in the reactor core.

The most common reactor design is the pressurized water reactor (PWR), representing 303 of the world's 422 currently operable nuclear power reactors.

DIFFERENCES AMONG POWER REACTOR DESIGNS

REACTOR DESIGN	FUEL	MODERATOR	COOLANT	QUANTITY
Pressurized water reactor (PWR)	Enriched UO_2	Water	Water	308
Boiling water reactor (BWR)	Enriched UO_2	Water	Water	61
Pressurized heavy water reactor (PHWR)	Natural UO_2	Heavy water	Heavy water	47
Advanced gas-cooled reactor (AGR)	Natural U and enriched UO_2	Graphite	Carbon dioxide	8
Light water graphite reactor (LWGR)	Enriched UO_2	Graphite	Water	11
Fast breeder reactor (FBR)	PuO_2 and UO_2	None	Liquid sodium	2
High temperature gas-cooled reactor (HTGR)	Enrichd UO_2	Graphite	Helium	1

SOURCES: World Nuclear Association. "Nuclear Power Reactors." 2023. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx.
IAEA Power Reactor Information System. "Country Statistics." 2023. https://www.iaea.org/PRIS/CountryStatistics/CountryStatisticsLandingPage.aspx.

NEXT-GENERATION REACTORS AND ADVANCED FUELS

Ongoing innovation ensures that nuclear remains among our best options for clean, reliable and affordable power.

In 2002, the Generation IV International Forum was established to oversee the development of six new reactor technologies:

1. Gas-cooled fast reactor (GFR)
2. Lead-cooled fast reactor (LFR)
3. Molten-salt reactor (MSR)
4. Sodium-cooled fast reactor (SFR)
5. Supercritical water-cooled reactor (SCWR)
6. Very high temperature reactor (VHTR)

All six designs offer improvements over existing reactors, including output flexibility, varying fuel options and reduced waste streams.

Four of the six reactor types are suitable for hydrogen production or other process heat, in addition to power generation.

Advanced fuel options include thorium, reprocessed uranium and mixed oxide fuel (MOX).

Thorium is a naturally occurring element more abundant in nature than uranium. Several types of reactors can already use thorium.

Reprocessed uranium (or recycled uranium) is uranium that has been recovered from used nuclear fuel and treated for re-use. It has the potential to reduce the volume of high-level waste.

MOX is made from plutonium recovered from used nuclear fuel and depleted uranium. MOX also provides a means of using and eliminating weapons-grade plutonium.

SOURCE: The Generation IV International Forum. "Generation IV Systems." 2020. https://www.gen-4.org.

SMALL MODULAR REACTORS

Designs of small modular reactors (SMRs) range between less than 1 megawatt to 300 megawatts, with the largest fitting in a school gym. They're also modular: they can be mass-produced, saving on costs and allowing for shipment to remote locations. A small city could use an SMR until it reaches capacity, then add another as the city grows. A mine could ship an SMR to help with its production, then move it when operations shut down.

The potential applications for SMRs in Canada include providing electricity to small and remote cities, providing process heat for resource industries such as Ontario's Ring of Fire mining and Alberta's oil sands, as well as contributing to existing power grids.

The deployment of SMRs in Canada would reduce greenhouse-gas emissions drastically, as nuclear power would, in many cases, replace fossil fuel generation.

About 70 SMR designs are now in development internationally. SMRs are under construction or in the licensing stage in Argentina, Canada, China, Russia, South Korea and the United States of America.

In 2020, the first working prototype SMR, Akademik Lomonosov, started generating energy at Russia's northeastern port town of Pevek.

SOURCE: International Atomic Energy Agency. "What are Small Modular Reactors (SMRs)? Nuclear Explained." 2023. https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.

SMRS, THE ENVIRONMENT, AND THE ECONOMY

Adding small modular reactors (SMRs) to the Canadian power mix could bring about several benefits.

Greener cities – SMRs could power smaller grids, especially in remote and northern communities normally powered by fossil fuels. As about 1 megawatt can power about 750 homes, an SMR could easily power a small city. Some designs could also add intermittent power, making wind and solar more feasible.

Hydrogen production – Many SMRs run hot enough to enable efficient generation of hydrogen, with enormous potential for low-carbon energy for transport.

Greener industry – Industries such as mining and the oilsands are a big part of Canada's economy, but they are often remote and off-grid, and they need a lot of heat and power to operate. This normally means burning fossil fuels. SMRs could lower the carbon emissions of these industries substantially.

Reliable electricity – SMR designs also allow for "islanding" parts of the electrical grid, meaning that a blackout in one region would be less likely to affect another, if it is powered by a nuclear reactor. An SMR could also be used to re-power a grid after a blackout, as it needs no other power source to restart.

District Heating – Off-grid power, district heating currently relies almost exclusively on diesel fuel, which has several limitations (e.g. cost, emissions). These needs may be addressed by very small SMRs.

Exports – The global market for SMR technology is estimated at $400 to $600 billion. Early leadership in SMR technology could secure a significant share of that market.

SOURCE: EnviroEconomics and Navius Research. "Emission and Economic Implications for Canada of Using Small Modular Reactors (SMRs) in Heavy Industry." 2021.

ADVANCING SMRS IN CANADA

With its large uranium reserves, extensive nuclear experience, and robust regulation, Canada has the potential to be a leader in the development, use, and sale of small modular reactor (SMR) technologies.

Interest in SMRs is rising across the country. In December 2019, the premiers of Saskatchewan, Ontario, and New Brunswick signed a memorandum of understanding (MOU) to advance the development and deployment of SMRs; Alberta joined the MOU in April 2021. The MOU encourages cooperation among the involved provinces and with industry—and action. This includes a feasibility study prepared by four provincial utilities, which found that SMRs have the potential to be economically competitive.

In 2022, the four provinces released "A Strategic Plan for the Deployment of Small Modular Reactors", which was soon followed the announcement that Saskatchewan is considering the deployment of an SMR in the early 2030s. Later that year, the Canada Infrastructure Bank struck a $970-million deal with Ontario Power Generation to build the country's first SMR in Clarington, Ontario. Along with existing SMR projects in Ontario and New Brunswick, Canada is positioning itself as a world leader on this innovative technology.

RADIOACTIVE WASTE AND TRANSPORTATION

RADIOACTIVE WASTE

Radioactive waste is any post-production solid, liquid or gas that emits radiation.

Industrial activity at uranium mines, mills, nuclear power plants, and research and medical facilities creates radioactive waste.

There are four classes of radioactive waste:

Uranium mine and mill waste consists of waste rock from uranium mining and tailings from uranium milling. Waste rock is the material removed from the mine to gain access to the uranium ore. Tailings are what remain of the ore after the uranium has been removed by a chemical process.

Low-level waste includes items such as mop heads, cloths, gloves and other protective clothing that may have been contaminated while being used in the workplace. Over 98% of the nuclear waste in Canada by volume is low-level waste.

Intermediate-level waste includes items that have had more direct contact with radioactive substances such as ion-exchange resins and reactor components.

High-level waste is used fuel. It is generated at nuclear power plants and is highly radioactive.

RADIOACTIVE WASTE IN CANADA

WASTE CATEGORY	INVENTORY TO END OF 2019
Waste rock	167,000,000 tonnes
Mill and mine tailings	218,000,000 tonnes
Low-level waste	2,524,670 m^3
Intermediate-level waste	15,681 m^3
High-level waste	12,718 m^3

SOURCE: Natural Resources Canada. "Canada's radioactive waste." 2023. https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/nuclear-energy-uranium/radioactive-waste/7719.

USED NUCLEAR FUEL

Used nuclear fuel is the spent fuel that is removed from a nuclear reactor.

Nuclear fuel bundles are removed from reactors when the concentration of U-235 inside the fuel becomes too low to sustain the fission reaction at the desired power level.

Once removed, used fuel is stored in water-filled pools for seven to ten years, giving it time to cool down and reduce its radioactivity.

After about ten years, nuclear fuel bundles emit less than 0.01% of the radioactivity of fuel fresh from the reactor.

Once the bundles have cooled down sufficiently, they are put into dry storage: large concrete containers that protect and cool the bundles and contain the remaining radiation.

Used nuclear fuel may be recycled to become usable again. Although this is not currently practised in Canada, fuel recycling is a part of several successful nuclear programs, including that of France.

USED FUEL BAY AT BRUCE B

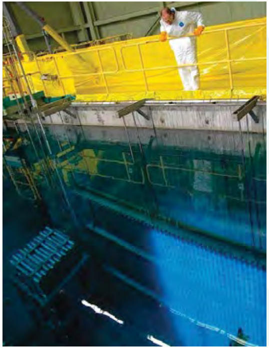


IMAGE: Bruce Power

DID YOU KNOW?

ONLY ABOUT 1% OF THE TOTAL ENERGY IN THE URANIUM IS USED BEFORE FUEL BUNDLES ARE REMOVED FROM THE REACTOR. THAT'S WHY MANY SCIENTISTS PREFER NOT TO REFER TO USED FUEL AS WASTE.

HOW USED NUCLEAR FUEL IS MANAGED

All of Canada's used nuclear fuel is safely managed at licensed storage facilities.

There are strict security measures in place to ensure that there is no threat to public health from stored used fuel bundles.

The storage of used nuclear fuel is managed by the utilities and laboratories that own the fuel, and is closely monitored, regulated and licensed by the Canadian Nuclear Safety Commission (CNSC), in direct cooperation with the International Atomic Energy Agency (IAEA).

The long-term care of Canada's used nuclear fuel is managed by the Nuclear Waste Management Organization (NWMO).

USED FUEL STORAGE CONTAINERS

IMAGE: Ontario Power Generation

DID YOU KNOW?

IF NUCLEAR ENERGY SUPPLIED ALL OF THE ELECTRICITY YOU'LL EVER USE IN YOUR LIFETIME, THE WASTE WOULD FIT IN A POP CAN!

NUCLEAR WASTE MANAGEMENT ORGANIZATION

In 2002, the Nuclear Waste Management Organization (NWMO) was established in response to federal legislation to develop a management approach for the long-term care of Canada's used nuclear fuel.

The NWMO engaged citizens, knowledge specialists and Indigenous peoples across Canada to determine the approach that would meet the priorities and objectives of Canadians. In 2007, the Government of Canada selected Adaptive Phased Management (APM) as Canada's plan. The NWMO is responsible for implementing this plan.

The end point of APM is the centralized containment and isolation of used nuclear fuel in a deep geological repository. The project will proceed only with the interested community, the local First Nation and Métis communities and the surrounding communities working in partnership to implement it.

The siting process is community-driven and designed to ensure, above all, that the selected site is safe and secure. It involves detailed technical and social studies to progressively narrow down to a single preferred site by 2023. As of 2021, two areas are still being studied, in South Bruce and Ignace, both in Ontario.

A safe, secure and socially acceptable transportation plan is also required.

As required by law, the producers of used nuclear fuel are responsible for fully funding the implementation of Canada's plan.

DID YOU KNOW?

AS WAS MANDATED BY THE *NUCLEAR FUEL WASTE ACT*, PRODUCERS OF USED NUCLEAR FUEL HAVE ALREADY CONTRIBUTED TO TRUST FUNDS THAT ENSURE THE LONG-TERM MANAGEMENT OF CANADA'S USED FUEL.

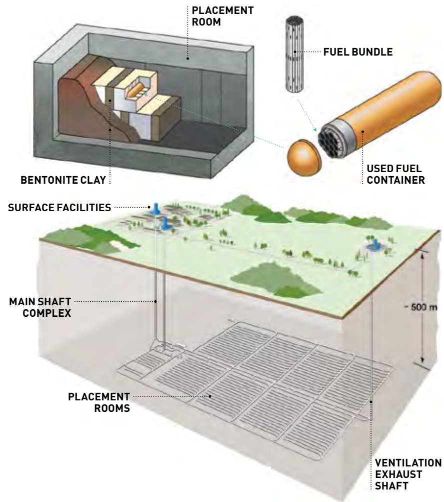
DEEP GEOLOGICAL REPOSITORY

Used nuclear fuel stored in a deep geological repository will be placed in secure containers approximately 500 m underground.

Advanced containers and secure geology will ensure that the public and environment are protected from radiation exposure.

The site selection process has been underway since 2010. This process started with 22 municipalities and Indigenous communities that expressed interest in learning more and exploring their potential to host the project.

DEEP GEOLOGICAL REPOSITORY SCHEMATIC



SOURCE: Nuclear Waste Management Organization. "Deep Geological Repository Conceptual Design Report Crystalline / Sedimentary Rock Environment." May 2016. https://www.nwmo.ca/~/media/Site/Reports/2016/06/08/10/03/APM_REP_00440_0015_R001.ashx?la =en.
Nuclear Waste Management Organization. "Study areas." 2023. https://www.nwmo.ca/en/Site-selection/Study-Areas

LOW- AND INTERMEDIATE-LEVEL WASTE

Nuclear-facility owners are responsible for the safe storage of their low- and intermediate-level waste. This waste—ranging from cleaning items used around a power plant to reactor parts—is much less radioactive than spent fuel, but there's a lot more of it.

This waste is now safely stored above ground at nuclear facilities, but this is not ideal, because it is exposed to natural hazards. The radioactivity of the low-level waste (98% of the total) will fall to safe levels within a few hundred years, but it would be difficult to guarantee stewardship of a site for so long.

Operators and experts agree that the best solution here is the same as for spent fuel: a deep geological repository.

Ontario Power Generation (OPG) is actively seeking a suitable location. This requires a stable rock formation—but also agreement by nearby communities, including First Nations, who understand the risks and benefits.

Scientific analysis shows that the risks are very low: a rock formation in Kincardine, Ontario once identified as a possible site, has been undisturbed for many millions of years. On the other hand, the repository would have to be managed, creating employment opportunities for nearby communities.

Managing several legacy sites on behalf of the federal government, Canadian Nuclear Laboratories (CNL) is taking a different approach for the Port Hope area, by removing low-level waste contamination from soil, backfilling with clean soil, then engineering and capping a storage mound. CNL is planning to build the Near Surface Disposal Facility, a containment mound to safely and permanently dispose of solid, low-level radioactive waste from legacy operations at the site.

SOURCES: "Deep Geologic Repository for Low and Intermediate Level Radioactive Waste Project." Canadian Environmental Assessment Agency. 2015.
Canadian Nuclear Safety Commission. "Low- and intermediate-level radioactive waste." 2023. http://nuclearsafety.gc.ca/eng/waste/low-and-intermediate-waste/index.cfm
"Near Surface Disposal Facility." Canadian Nuclear Laboratories. 2023. https://www.cnl.ca/environmental-stewardship/near-surface-disposal-facility-nsdf/
"Port Hope Area Initiative." Canadian Nuclear Laboratories. 2023. https://www.phai.ca/en/home/default.aspx

TRANSPORTATION

Every year around the world, about 20 million shipments containing radioactive substances are transported on public roads, railways and ships.

Canada has extensive experience in transporting fuel cycle materials, including uranium ore, fuel bundles, tritiated water and used fuel, as well as non-fuel cycle materials such as radioisotopes.

Measures that contribute to the safe management of radioactive substances include:

- safe engineering of vehicles and containers;
- qualified personnel receiving sound training;
- inventory tracking and accountability;
- independent, professional regulatory bodies; and
- careful study and analysis of incidents.

The Canadian Nuclear Safety Commission (CNSC) and Transport Canada share the responsibility for the safe transportation of nuclear substances.

In Canada's history, there has never been a transportation accident that has resulted in radioactive release causing harm to any individual or the environment.

DID YOU KNOW?

ONLY ABOUT 5% OF RADIOACTIVE SHIPMENTS ARE RELATED TO THE FUEL CYCLE. THE REST RELATE TO SUCH SECTORS AS MEDICINE, AGRICULTURE, INDUSTRY AND RESEARCH.

SOURCES: International Atomic Energy Agency. "Transport Security." 2023. https://www.iaea.org/topics/transport-security.
World Nuclear Transport Institute. "Nuclear Power." 2023. https://www.wnti.co.uk/nuclear-transport-facts/facts-figures.aspx.

TYPES OF PACKAGES

For the packaging of radioactive substances, Canada has adopted the standards of the International Atomic Energy Agency (IAEA), which are based on the characteristics of the material they contain.

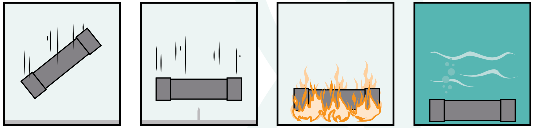
Excepted and industrial packages are sufficient for low-activity materials such as uranium ore.

Type A packages are designed to withstand minor accidents and are used for medium-activity materials such as radioisotopes.

Type B packages are robust and very secure casks for high-activity materials such as used nuclear fuel and radioactive waste. These packages undergo stringent testing, including free-drop testing, puncture testing, thermal testing and immersion testing.

Type C packages offer the greatest protection in accident scenarios. They are used to transport highly hazardous materials such as plutonium and can survive being dropped from an aircraft at cruising altitude.

TYPE B PACKAGE TESTS



FREE DROP
A 9-m (30-foot) free-fall onto an unyielding surface

PUNCTURE
A 1-m (40-inch) free-fall onto a steel rod

THERMAL
A 30-minute, fully engulfing fire at 800°C (1,475°F)

IMMERSION
An 8-hour immersion under water

NUCLEAR SCIENCE AND TECHNOLOGY

NUCLEAR SCIENCE AND TECHNOLOGY IN CANADA

Nuclear science and technology is an integral part of Canada's manufacturing and engineering capability. That is why the federal government and Canada's nuclear industry have a long history of investing in nuclear science and technology.

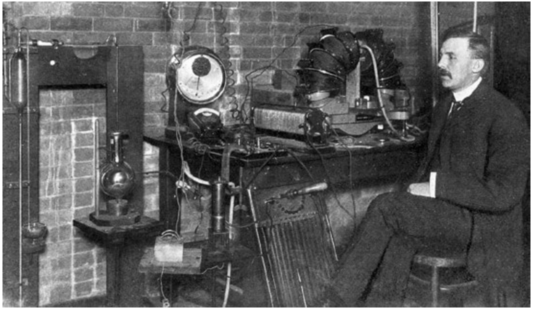
Nuclear research initiatives take place at national laboratories, universities and research reactors across the country.

Canada is a historic leader in nuclear research and is home to four Nobel prizes related to nuclear science and technology:

- Ernest Rutherford in 1908 for his work at McGill University on radioactive decay;
- Richard E. Taylor in 1990 for early understandings of quarks in particle physics;
- Bertram N. Brockhouse in 1994 for developing new neutron scattering techniques; and
- Arthur B. McDonald in 2015 for the discovery of neutrino oscillations, showing that neutrinos have mass.

Nuclear technology plays an important role in numerous sectors across Canada, including medicine, food, agriculture, industry, water resources, transportation and consumer products.

ERNEST RUTHERFORD AT MCGILL IN 1905



RADIOISOTOPES AND HALF-LIVES

Nuclear technology is based on the use of radioisotopes—radioactive isotopes of an element.

All isotopes of a given element have the same number of protons in their atomic nuclei but differing numbers of neutrons.

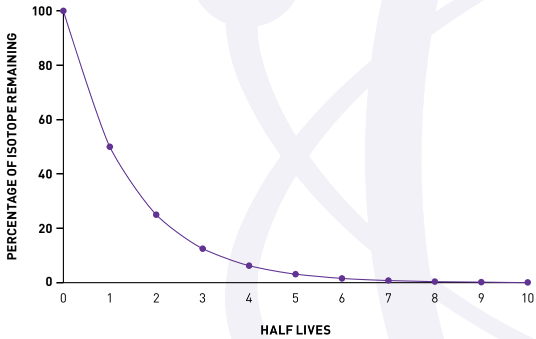
Radioisotopes are isotopes that have an unstable number of neutrons and undergo a change (or "decay") to become stable, emitting radiation in the process.

A half-life is the time it takes for half of a radioisotope to decay. The shorter the half-life, the faster the isotope decays and the more radioactive it is.

Uranium-235 is used to make fuel. U-235 has a very long half-life of 704 million years, which is why unused fuel bundles can be safely handled by people.

Radioisotopes that are commonly used in medicine include fluorine-18, which has a half-life of just under two hours, and technetium-99, which has a half-life of six hours.

RADIOACTIVE DECAY



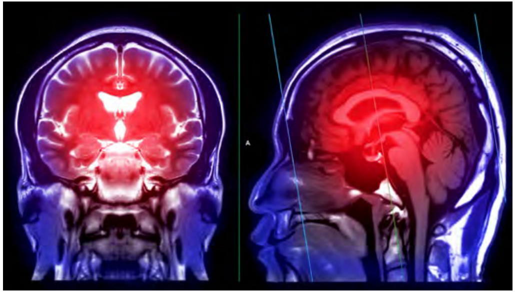
NUCLEAR MEDICINE

Nuclear medicine uses radiation to diagnose and determine the stages of various diseases, including cancer, and to treat illness, particularly by destroying tumours with radiation therapy. Much of nuclear medicine works by injecting a radioisotope into the patient. This isotope accumulates in target tissues and emits radiation that is picked up by a detector outside the body.

Over 1.3 million diagnostic scans are performed each year in Canada, using radioisotopes such as technetium-99. Canada has a history as a world leader in medical isotopes, contributing most of the world's raw materials until the closure of the National Research Universal Reactor in 2018. However, in the same year, Canada announced the Institute for Advanced Medical Isotopes at the TRIUMF facility in the University of British Columbia, with plans to produce a variety of medical isotopes.

There are 20 medical isotopes approved for use in Canada. Some, such as fluorine-18 and gallium-67, are produced at select sites across Canada. Others, such as technetium-99 and iodine-131, must presently be imported.

DIAGNOSTIC SCAN OF THE BRAIN



SOURCES: Canadian Institutes of Health Research. "Medical Imaging." 2015. http://www.cihr-irsc.gc.ca/e/40539.html.
Natural Resources Canada. "Medical Isotopes." 2023. https://www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/nuclear-energy-uranium/medical-isotopes/23060
World Nuclear News. "Canada to build advanced medical isotope centre." 2018. https://www.world-nuclear-news.org/Articles/Canada-to-build-advanced-medical-isotope-centre.

RADIATION THERAPY AND STERILIZATION

Nuclear medicine includes a common set of techniques used to treat cancer. They work by delivering radiation to specific areas of the body to destroy cancer cells.

Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis.

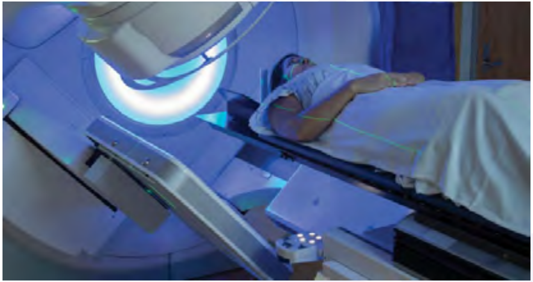
Radiation therapy can be performed either externally by irradiation or internally by radioisotope injection.

Thousands of therapeutic doses are administered each year in Canada. This can be done by external beam radiation, which focuses radiation directly on cancerous tissue, or by brachytherapy, which involves placing a radiation source inside or next to the affected tissue.

Hospitals also use radioisotopes such as cobalt-60, which is produced in nuclear power plants in Ontario, to sterilize medical equipment such as gowns, gloves, masks, syringes and implants.

Sterilization by radiation is less expensive than traditional heat sterilization, doesn't cause heat damage and is safer because it can be done after the items have been packaged. Nor does it cause the sterilized equipment to become radioactive—it's perfectly safe to handle right away.

PATIENT UNDERGOING RADIATION THERAPY



SOURCE: "The Canadian Medical Imaging Inventory 2019–2020." Canadian Health Technology Review. January 2021.

ENABLING THE HYDROGEN ECONOMY

Hydrogen promises enormous advantages for powering Canadian industry. When combined with oxygen freely available in the air, it releases energy, which can be turned into electricity—and the only waste product is water. So, it could be used to transform the Canadian economy:

- Hydrogen fuel cells could power vehicles with no carbon emissions.
- Hydrogen could power large industry in remote locations without burning fossil fuels.
- Hydrogen could store energy from intermittent power sources such as wind or solar, then supply electricity at night or when the wind isn't blowing.

The main method for production worldwide depends on using natural gas, a fossil fuel. Hydrogen can also be produced by electrolyzing (splitting) water molecules. This uses electricity, but the process itself uses some of the energy, so it's more carbon-intensive than the electricity used to produce it.

As nuclear power releases less carbon than almost any other source of electricity, it is possible to use it to make relatively "green" hydrogen.

Another process, called "methane pyrolysis" uses heat to strip the hydrogen atoms from methane, producing hydrogen gas. It also leaves carbon as a by-product, but this carbon is solid, so it does not enter the atmosphere.

This method needs high temperatures (500-1000°C), which can be achieved by Generation-IV nuclear reactors, including some small modular reactor designs. This shows potential as a cost-effective way to produce hydrogen without high carbon emissions.

Transforming the economy will require a lot of hydrogen: to do this in the European Union, the European Commission wants to produce 10 million tonnes of renewable hydrogen by 2030.

CANADA AND THE HYDROGEN ECONOMY

Canada is well placed to help supply hydrogen for its own market and internationally, being already one of the top 10 hydrogen producers in the word and a top-tier nuclear nation.

The federal government recognizes Canada's potential as both a supplier and a leader in hydrogen technology. In December 2020, it launched the Hydrogen Strategy for Canada as part of its commitment to net-zero emissions by 2050. The Strategy explicitly recognizes the potential of the nuclear industry in a hydrogen economy.

In the 2022 Fall Economic Statement, the government intends for the new investment tax credit to be available across a range of clean hydrogen pathways. The proposed tax credit will be refundable, and available for eligible investments. The credit will be phased out after 2030.

"HYDROGEN'S MOMENT HAS COME. THE ECONOMIC AND ENVIRONMENTAL OPPORTUNITIES FOR OUR PROUD ENERGY WORKERS AND COMMUNITIES ARE REAL. THERE IS GLOBAL MOMENTUM, AND CANADA IS HARNESSING IT. THIS IS HOW WE GET TO NET ZERO."

— **SEAMUS O'REGAN**,
Former Minister of Natural Resources

SOURCE: Government of Canada. "Consultation on the Clean Hydrogen Investment Tax Credit." 2023. https://www.canada.ca/en/department-finance/programs/consultations/2022/consultation-on-the-investment-tax-credit-for-clean-hydrogen.html.

FOOD IRRADIATION

Food irradiation is the process of using radiation to kill bacteria, insects and parasites that can cause food-borne diseases.

Food irradiation also extends the shelf-life of food by destroying the micro-organisms that cause spoilage and by slowing the ripening process. It does not cause the food itself to become radioactive: radiation simply passes through the food.

More than 55 countries, including Canada, irradiate food products such as meat, fruit, vegetables, grains and spices.

The Canadian firm Nordion has built many of the food irradiators around the world.

DID YOU KNOW?

YEARS OF RESEARCH HAS SHOWN IRRADIATED FOOD TO BE JUST AS SAFE AND NUTRITIOUS AS FOOD PRESERVED BY FREEZING OR CANNING!

AGRICULTURAL APPLICATIONS OF RADIATION

Radiation is used in agriculture to produce more desirable crop varieties and reduce crop losses due to insects.

Crop varieties are produced by exposing seeds to radiation to induce genetic changes, a process known as mutation breeding.

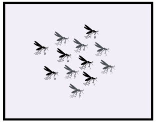
Mutation breeding has been used for several decades to create crops that are more plentiful, nutritional, adaptable to harsh climates and resistant to pests. Over 3,200 crop varieties have been developed this way.

Radiation is used to control insect populations via the Sterile Insect Technique (SIT).

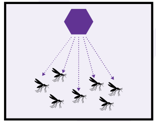
SIT is an environmentally friendly alternative to pesticides that involves rearing, sterilizing and releasing male insects into the wild, where they mate with females but produce no offspring.

Certain fertilizers also contain trace amounts of radioactive elements to determine nutrient absorption rates and improve water and fertilizer management.

STERILE INSECT TECHNIQUE

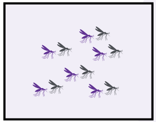


Mosquitoes are mass-reared

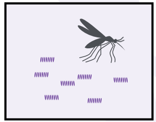


Male mosquitoes are isolated and sterilized

Sterilized males are released into the wild



Sterilized males mate with wild females



Wild females lay infertile eggs

SOURCE: International Atomic Energy Agency. "Mutation Breeding." 2019. https://www.iaea.org/topics/mutation-breeding.

INDUSTRIAL INSPECTIONS

Radioactive materials are used to examine the molecular and macroscopic structure of materials without damaging or changing them. This is a form of non-destructive testing.

Like x-rays, gamma rays pass through objects and create images of them on film, revealing material flaws.

Applications of these nuclear images include:

- studying critical aircraft components such as rotors, wings and landing gear to reduce their chance of in-flight failure;
- examining the structure of automotive engines so that they can be made more reliable and with fewer defects;
- improving the surface structure of medical implants such as pacemakers so that they are more compatible with the human body;
- analyzing pipes and other oil and gas components to decrease defects, thereby avoiding leaks and benefitting environmental and human health; and
- developing sophisticated delivery systems for pharmaceuticals to make them more effective and reduce side effects.

INDUSTRIAL GAUGES AND TRACERS

A nuclear gauge is a device that uses a radioactive source to quickly detect characteristics of an item such as thickness, density or chemical makeup.

There are two main types of gauges: fixed and portable.

Fixed gauges are typically used in production facilities to control and monitor product quality.

Portable gauges are brought to work sites for assorted reasons, including:

- analyzing the walls of dug holes to identify mineral deposits;
- searching for underground caves or other formations that could make a building site unstable; and
- determining the density of asphalt in paving mix to optimize road life, rutting resistance and overall durability.

Radioisotopes are used as tracers to study the mixing and flow rates of various liquids, powders and gases, and to locate leaks.

For ground and surface water resources, tracers can help determine characteristics such as age, origin, distribution and interconnections, and identify discharge and sedimentation rates.

MOISTURE/DENSITY GAUGE

IMAGE: Humboldt Scientific

DID YOU KNOW?

THE CANADIAN NUCLEAR SAFETY COMMISSION (CNSC) REGULATES THE POSSESSION, USE, PACKAGING, TRANSPORTATION, STORAGE, IMPORTING AND EXPORTING OF ALL TYPES OF NUCLEAR SUBSTANCES, INCLUDING NUCLEAR GAUGES.

NUCLEAR DESALINATION

Most Canadians are fortunate to have ready access to fresh water. However, in many parts of the world, potable water is in short supply.

As of 2020, 17,000 desalination plants were operating in about 150 countries to produce safe drinking water.

Most desalination plants are powered by burning fossil fuels, which contributes to increased greenhouse-gas emissions.

Nuclear desalination plants use the heat from small nuclear reactors to evaporate water, leaving the salt and debris behind.

Though there are several desalination methods available, nuclear desalination offers carbon-free heat and low fuel costs.

There are several small demonstration nuclear desalination plants in operation, but so far no large-scale commercial deployments.

DID YOU KNOW?

IT IS ESTIMATED THAT ONE FIFTH OF THE WORLD DOES NOT HAVE ACCESS TO SAFE DRINKING WATER.

SOURCES: International Desalination Association. "Desalination and Water Reuse by the Numbers." 2019. https://idadesal.org/.

World Nuclear Association. "Desalination." 2020. http://www.world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-desalination.aspx.

Eke, Joyner, Tusuf, Ahmed, Giwa, Adewale & Soiq, Ahmed (2020). The global status of desalination: An assessment of current desalination technologies, plants and capacity. https://www.sciencedirect.com/science/article/abs/pii/S0011916420313114.

NUCLEAR-POWERED TRAVEL

SPACE TRAVEL

Nuclear power has been used for space travel since 1961.

Radioisotope thermal generators are used in most space missions. The heat generated by the decay of a radioactive source, often plutonium, is used to generate electricity.

The Voyager space probes, the Cassini mission to Saturn, the Galileo mission to Jupiter, the New Horizons mission to Pluto and the Curiosity and Perseverance missions to Mars were all powered by these generators.

NASA is considering new nuclear propulsion designs proposed by BWX Technologies partnered with Lockheed Martin, General Atomics Electromagnetic Systems partnered with X-energy and Aerojet Rocketdyne, and Ultra Safe Nuclear Technologies partnered with GE Hitachi, General Electric Research, and others.

MARINE TRAVEL

Nuclear power is particularly suitable for vessels that need to be at sea for extended periods of time without refuelling.

Currently, there are over 140 nuclear-powered vessels. Most of these are submarines, but there are also nuclear-powered icebreakers and aircraft carriers.

SOURCE: World Nuclear Association. "The Many Uses of Nuclear Technology." 2020. http://www.world-nuclear.org/information-library/non-power-nuclear-applications/overview/the-many-uses-of-nuclear-technology.aspx.
World Nuclear Association. "Nuclear-Powered Ships." 2023. https://world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx.

CONSUMER PRODUCTS

Smoke detectors are the most common consumer products that use nuclear technology. The ionization type of smoke detectors use the radiation from a small amount of americium-241 to detect the presence of smoke or heat.

Emergency exit signs are powered by tritium, a radioactive isotope of hydrogen. These signs do not require electricity or batteries, and therefore serve an important safety function during power outages.

Tritium, which is generated in CANDU-type fission reactors, is also used in clocks, watches and gun sights to create light in the absence of electricity.

Other consumer products that use nuclear technology include:

- cosmetics, such as contact lens solutions and hair products, which are sterilized with radiation;
- frying pans, which are often treated with radiation to achieve a non-stick surface; and
- photocopiers, which sometimes use radioactive polonium to prevent static build-up.

HOW IONIZATION SMOKE DETECTORS WORK

Alpha radiation from an americium source ionizes the air between two electrodes (+ and -). This allows current to flow from one electrode to another. When there is smoke in this space, the ions do not flow, and the current stops. This triggers the smoke detector to set off an alarm.

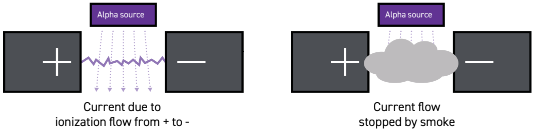


IMAGE: Teaching Advanced Physics

SOURCE: World Nuclear Association. "Radioisotopes in Consumer Products." 2018. http://www.world-nuclear.org/information-library/non-power-nuclear-applications/radioisotopes-research/radioisotopes-in-consumer-products.aspx.

OTHER USES OF NUCLEAR TECHNOLOGY

The applications of nuclear technology are vast and, in addition to those already described, include:

- preventing the spread of infectious diseases such as Ebola, malaria and Zika;
- measuring magnitudes and sources of soil erosion;
- detecting, monitoring and tracking food contaminants;
- improving livestock health, productivity and nutrition;
- combatting malnutrition and childhood obesity;
- analyzing metals, alloys and electronic materials;
- identifying extremely small and diluted forensic materials;
- characterizing archaeological and historical materials;
- carbon-dating rocks and organic materials; and
- studying air pollution and aerosols.

SOURCE: International Atomic Energy Association. "Material Analysis." 2019. https://www.iaea.org/topics/material-analysis.

NUCLEAR RESEARCH CENTRES

Nuclear research centres are key facilities for promoting nuclear science and technology.

There are several major nuclear research centres in Canada, five of which use research reactors. Other centres rely on particle accelerators, including linear accelerators, cyclotrons and synchrotrons.

Canadian Nuclear Laboratories (CNL) is a world leader in the development of innovative nuclear science and technology products and services. By leveraging the assets owned by Atomic Energy of Canada Limited (AECL), CNL also serves as the nexus between government, the nuclear industry, the broader private sector and the academic community.

Canada's largest nuclear research centre is the Chalk River Laboratories, owned by AECL and operated by CNL. The Chalk River Laboratories boast multiple licence-listed nuclear facilities, including the ZED-2 Research Reactor, the Biological Research Facility, and the Tritium Facility, as well as more than 50 other research facilities and laboratories that support innovation in safety, security, health, the environment and clean energy. Enabled by a $1.2 billion investment from Atomic Energy of Canada Limited and the Government of Canada, the campus is undergoing significant revitalization with a new hydrogen laboratory opening in 2015, a new materials science laboratory complex in 2016, and construction is underway on the Advanced Nuclear Materials Research Centre (ANMRC), which will become Canada's largest single laboratory facility dedicated to nuclear and radioactive materials handling and research.

CNL is also leading Canada's efforts to safely address a number of legacy nuclear liabilities, including the decommissioning of prototype reactors, clean up of historic wastes, and the construction of Canada's first low-level waste disposal facility.

Nuclear research is also carried out at Canadian universities. TRIUMF, for example, is located in the University of British Columbia but is the product of many universities' efforts. TRIUMF operates the world's most powerful cyclotron, enabling Canadian research in atomic physics and new methods of producing radioisotopes. TRIUMF also hosts the Institute for Advanced Medical Isotopes, a new, state-of-the-art facility for research into next-generation medical isotopes and radiopharmaceuticals.

Likewise, McMaster University is home to a suite of nuclear research facilities, including a 5-MW test reactor, enabling discoveries in clean-energy technology, medicine, advanced materials, nuclear safety, and environmental science. McMaster is also a global leader in medical isotope research and production, contributing to treatment for more than 70,000 cancer patients every year.

Canadian Light Source operates Canada's only synchrotron, a large and complex ring-shaped device that accelerates electrons for materials research.

CHALK RIVER LABORATORIES

IMAGE: Canadian Nuclear Laboratories

FUSION RESEARCH

Fusion is a form of nuclear energy with the potential to create massive amounts of heat by forcing atomic nuclei together. It is essentially the opposite of fission, which involves splitting atoms apart.

In the sun, gravity creates the conditions for fusion. Here on earth, the challenge is to create these same conditions by using magnetic fields and inertia.

One of the most efficient fuels for fusion power is a mix of heavy hydrogen isotopes (deuterium and tritium), which means that water could become a primary fuel source.

In addition to having an abundant fuel source, fusion has the potential for even cleaner operation and shorter-lived radioactive waste than fission.

General Fusion, a Canadian company based in British Columbia, is developing first-of-a-kind fusion demonstration facility that showcase their Magnetized Target Fusion technology.

NUCLEAR FUSION

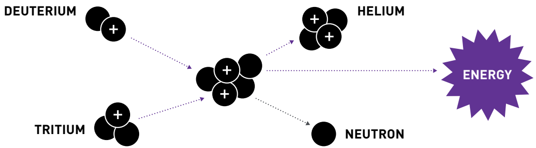


IMAGE: General Fusion

RADIATION, NUCLEAR SAFETY AND SECURITY

RADIATION

Radiation is energy that travels in the form of waves or particles. It can be found everywhere in the universe, including in rocks on the earth and in deep space.

Some types of radiation that can be directly sensed by humans are sound, light and heat. Other types can only be observed indirectly, such as microwaves, radio waves and ionizing radiation.

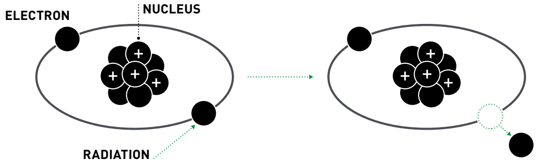
When radiation is discussed in the context of nuclear energy, it is typically referring to ionizing radiation.

Ionizing radiation is released when atoms decay. It is a highly energetic type of radiation that can detach electrons from atoms in the irradiated material.

Ionizing radiation occurs naturally and can be found all around us. The normal level of radiation at any given location is called background radiation.

Within the context of nuclear safety and human health, the most relevant types of radiation are alpha particles, beta particles and gamma rays.

IONIZING RADIATION



RADIATION DOSES AND EFFECTS

There are many different ways of measuring radiation. Alpha, beta and gamma radiation can be counted with a Geiger counter. Accumulated radiation dose can be measured over time with a personal dosimeter.

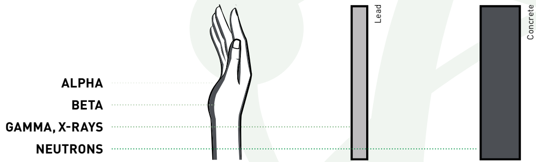
Different types of ionizing radiation have different biological effects. To account for these differences, the biological effects of ionizing radiation are generally measured in units called millisieverts (mSv).

Ionizing radiation cannot make non-radioactive material radioactive. This is why it is safe to use in sterilizing food and medical supplies.

High doses of ionizing radiation, however, can damage healthy tissues and cause serious illness.

While a safe level of radiation has not been conclusively established, research shows that radiation doses of up to 100 mSv/year have no measurable health effects in humans.

THE PENETRATING POWER OF DIFFERENT TYPES OF RADIATION



BACKGROUND RADIATION

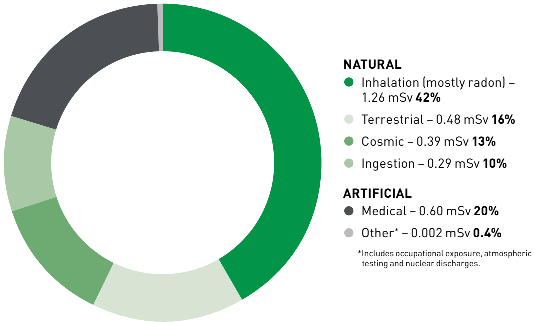
Background radiation is made up of natural and artificial (human-made) sources.

Natural background radiation worldwide is on average 2.4 mSv/year, though local variations can be significant. In some places, such as Ramsar in Iran, natural radiation levels can reach 260 mSv/year—over five times the dose limit for Canadian nuclear energy workers.

Canadians, on average, are naturally exposed to about 1.8 mSv/year. Local levels vary from about 1.3 mSv in Vancouver to about 4.1 mSv in Winnipeg. Most of this radiation comes from rocks in the ground and from naturally occurring radon gas.

Radiation from nuclear power produces less than 0.1% of our background radiation.

GLOBAL SOURCES OF RADIATION



SOURCES: Canadian Nuclear Safety Commission. "Radiation Doses." 2020. http://www.nuclearsafety.gc.ca/eng/resources/radiation/introduction-to-radiation/radiation-doses.cfm.
United Nations Scientific Committee on the Effects of Atomic Radiation. "Radiation Effects and Sources." 2016, p. 54. http://www.unscear.org/docs/publications/2008/UNSCEAR_2008_Report_Vol.I.pdf.

EFFECTS OF RADIATION ON THE BODY

While the low doses we receive naturally and through medical procedures pose little risk to our health, high doses received in a short time (called acute doses) can be very dangerous.

Doses at these magnitudes occur only in extreme circumstances, such as in the case of emergency workers after the Chernobyl accident. Canada has never had any event-producing doses of this magnitude.

DID YOU KNOW?

LIFE ON EARTH EVOLVED IN A RADIATION FIELD, AND SOME RESEARCH SHOWS THAT OUR CELLS HAVE THE ABILITY TO REPAIR DAMAGE DONE BY RADIATION!

RADIATION DOSES AND EXAMPLES

mSv	EXAMPLE
10,000	Acute dose that would be fatal within weeks
6,000	Acute dose to some Chernobyl emergency workers
5,000	Acute dose that would be fatal to half of those exposed within months
1,000	Acute dose that would cause radiation sickness, but not death
600	Maximum hourly dose recorded at Fukushima on 14 March 2011
350	Dose to Chernobyl residents who were relocated
150	Annual dose to astronauts on the International Space Station

mSv	EXAMPLE
50	Annual dose limit for nuclear energy workers
10	Dose from a full-body CT scan
1.8	Annual dose to Canadians from natural background radiation
1.0	Average annual dose to nuclear energy workers
0.1	Dose from a chest x-ray
.01	Dose from a dental x-ray
.001	Annual dose from living near a Canadian nuclear power plant

NUCLEAR SAFETY

Canada's nuclear power program has an exemplary safety track record, with over 60 years of occupational and public health and safety, and is a leader in the industry worldwide.

There are many layers of protection between nuclear facilities and the communities in which they operate. These layers of protection ensure the safety of workers, communities and the environment against any potential incident that could be caused by human error, equipment failure or external forces such as earthquakes.

Nuclear power generation is the only energy technology for which there is an international oversight agency at the United Nations: the International Atomic Energy Agency (IAEA).

Because of stringent monitoring and regulation at the national and international levels, nuclear power generation is one of the safest energy technologies.

DID YOU KNOW?

NUCLEAR POWER TECHNOLOGY HAS ONE OF THE LOWEST RATE OF FATALITIES AND INJURIES PER UNIT OF GENERATED ELECTRICITY!

NUCLEAR REGULATION

The Canadian Nuclear Safety Commission (CNSC) is Canada's nuclear regulator.

The CNSC is an independent agency that reports to Parliament through the Minister of Natural Resources. The CNSC has quasi-judicial powers, similar to a court of law, and can impose legal penalties such as fines on individuals and organizations.

The CNSC is responsible for regulating the use of nuclear energy and materials to protect the health, safety and security of people and the environment.

The CNSC monitors and regulates a diverse nuclear fuel cycle and other uses of nuclear material, including uranium mines, mills, processing facilities, fuel fabrication plants, nuclear power facilities, radioactive waste management facilities, nuclear research facilities, and facilities for processing nuclear substances.

Any person or organization that wants to possess, use, transport or store nuclear material—or build, operate, decommission or shut down a nuclear facility, including a nuclear power facility—must first obtain a licence issued by the CNSC.

The CNSC also implements Canada's international commitments on the peaceful use of nuclear energy.

The CNSC has a long-standing history of international bilateral and multilateral cooperation, particularly with the IAEA and the Nuclear Energy Agency (NEA). The CNSC participates in or leads many IAEA and NEA committees, working groups and forums, where lessons learned and best practices are shared. The CNSC also regularly hosts and participates in IAEA international peer reviews.

WHAT THE CNSC IS FOCUSED ON?

To ensure the safety of people and the environment, the CNSC is conducting compliance activities, including inspections, to ensure licensees adhere to all licence conditions and requirements.

The CNSC is performing a number of environmental assessments (EAs) under the *Canadian Environmental Assessment Act*, 2012 (CEAA 2012) and licensing reviews under the *Nuclear Safety and Control Act*. These include:

- the environmental assessments and licensing reviews of Canadian Nuclear Laboratories' proposed environmental remediation projects;
- the siting and construction of a near surface disposal facility at Chalk River Laboratories (CRL), Ontario;
- the decommissioning of the Nuclear Power Demonstration reactor in Rolphton, Ontario; and
- the decommissioning of the WR-I reactor at the Whiteshell Laboratories in Pinawa, Manitoba.

The CNSC is performing an EA under CEAA 2012 for Global First Power's Micro Modular Reactor project at the CRL site. The CNSC is continuing its readiness work in anticipation of proposed project applications for small modular reactors, including international collaboration to enhance safety and advance harmonization.

CNSC INSPECTION AT A NUCLEAR GENERATING STATION

IMAGE: Canadian Nuclear Safety Commission

DID YOU KNOW?

CNSC STAFF ARE LOCATED AT EVERY CANADIAN NUCLEAR GENERATING STATION, AS WELL AS AT CHALK RIVER LABORATORIES AND AT FIVE REGIONAL OFFICES ACROSS CANADA.

SITE SECURITY

Nuclear security in Canada is regulated by the CNSC, which sets out detailed security requirements for licensed nuclear facilities.

The security requirements are designed to safeguard nuclear facilities against the possibility of infiltration or attack, and to ensure that nuclear material stays in the right hands.

The main security requirements include:

- annual threat and risk assessments;
- on-site armed response forces available 24 hours a day, seven days a week at high-security sites;
- enhanced security screenings of employees and contractors involving background, police and security checks;
- enhanced access controls to nuclear facilities;
- design basis threat analyses for nuclear facilities;
- uninterrupted power supplies in place for alarm monitoring and other security systems; and
- contingency planning, drills and exercises.

BRUCE POWER RESPONSE FORCE

IMAGE: Bruce Power

SOURCE: Canadian Nuclear Safety Commission. "Emergency management and nuclear security." 2014. http://suretenucleaire.gc.ca/eng/resources/emergency-management-and-safety/index.cfm.

CYBERSECURITY

Cybersecurity is the practice of protecting systems, networks and programs from digital attacks.

Every critical infrastructure, including that of a power plant, relies on effective cybersecurity measures to protect against attacks.

The CNSC requires nuclear power plant licensees to have a cyber security program that meets the requirements of CSA N290.7-14, *Cyber security for nuclear power plants and small reactor facilities*. It conducts inspections to confirm compliance and program adequacy.

The safety and control systems of Canadian nuclear reactors and other vital plant components are not directly connected to business networks or the Internet.

HEADS OF STATE AT THE 2016 NUCLEAR SECURITY SUMMIT

IMAGE: Ben Solomon/U.S. Department of State

RESOURCES

CANADIAN UNIVERSITIES AND COLLEGES WITH NUCLEAR PROGRAMS

Algonquin College	algonquincollege.com
Brock University	brocku.ca
Carleton University	carleton.ca
McMaster University	mcmaster.ca
Ontario Tech University	ontariotechu.ca
Polytechnique Montréal	polymtl.ca
Queen's University	queensu.ca
Royal Military College of Canada	rmc-cmr.ca/en
University of Calgary	ucalgary.ca
University of Guelph	uoguelph.ca
University of British Columbia	ubc.ca
University of New Brunswick	unb.ca
University of Saskatchewan	usask.ca
University of Toronto	utoronto.ca
University of Waterloo	uwaterloo.ca
University of Western Ontario	uwo.ca
University of Windsor	uwindsor.ca

SHOULD YOUR SCHOOL BE LISTED HERE?

If we've missed a program with nuclear related education, let us know at info@cna.ca.

MCMASTER NUCLEAR REACTOR CORE

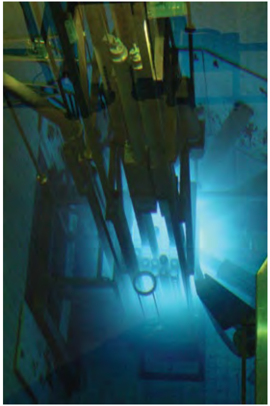


IMAGE: MCMASTER UNIVERSITY

DID YOU KNOW?

THE REACTOR CORE AT MCMASTER UNIVERSITY IS AMONG THE FEW WORLDWIDE THAT ARE VISIBLE AND ACCESSIBLE DURING OPERATION!

OTHER RESOURCES

Atomic Energy of Canada Limited	aecl.ca
Babcock Canada	babcockcanada.com/cavendish-nuclear
Bruce Power	brucepower.com
Cameco	cameco.com
Canadian Electricity Association	electricity.ca
Canadian Nuclear Isotope Council	canadianisotopes.ca
Canadian Nuclear Laboratories	cnl.ca
Canadian Nuclear Safety Commission	nuclearsafety.gc.ca
Canadian Nuclear Society	cns-snc.ca
Canadian Nuclear Workers Council	cnwc-cctn.ca
CANDU Owners Group	candu.org
Energy Council of Canada	energy.ca
General Fusion	generalfusion.com
Hydro Québec	hydroquebec.com
Independent Electricity Systems Operator	ieso.ca
International Atomic Energy Agency	iaea.org

International Commission on Radiological Protection	icrp.org
International Energy Agency	iea.org
Natural Resources Canada	nrcan.gc.ca
New Brunswick Power	nbpower.com
Nordion	nordion.com
North American Young Generation in Nuclear	naygn.org
Nuclear Energy Institute	nei.org
Nuclear Industry Association	niauk.org
Nuclear Waste Management Organization	nwmo.ca
OECD Nuclear Energy Agency	oecd-nea.org
Ontario Power Generation	opg.com
Ontario's Nuclear Advantage	ontariosnuclearadvantage.com
Organization of Canadian Nuclear Industries	ocni.ca
Saskatchewan Mining Association	saskmining.ca
SNC-Lavalin	snclavalin.com
Society for the Preservation of Canada's Nuclear Heritage	nuclearheritage.ca
Statistics Canada	statcan.gc.ca
Sylvia Fedoruk Canadian Centre for Nuclear Innovation	fedorukcentre.ca

TRIUMF	triumf.ca
United Nations Scientific Committee on the Effects of Atomic Radiation	unscear.org
U.S. Energy Information Administration	eia.gov
Women in Nuclear Canada	canada.womeninnuclear.org
World Health Organization—Radiation	who.int/health-topics/radiation
World Nuclear Association	world-nuclear.org
World Nuclear Transport Institute	wnti.co.uk

ABOUT THE CNA

The Canadian Nuclear Association (CNA) has been the national voice of the Canadian nuclear industry since 1960. Working with our members and all communities of interest, the CNA promotes the industry nationally and internationally, works with governments on policies affecting the sector and endeavours to increase awareness and understanding of the value nuclear technology brings to the environment, economy and daily lives of Canadians.

The Canadian Nuclear Factbook has been published regularly since 2004 by the Canadian Nuclear Association.

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THE CANADIAN NUCLEAR

FACTBOOK