THE CANADIAN NUCLEAR

# FACTBOOK

2017

CNA CANADIAN NUCLEAR ASSOCIATION

# THE CANADIAN NUCLEAR
# FACTBOOK
2017

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The information in this book is based on data available as of October 2016.

## MESSAGE FROM THE PRESIDENT

I am very pleased to present the 2017 edition of the Canadian Nuclear Factbook.

Over the years, this booklet has become a highly regarded reference on nuclear facts in Canada and worldwide. Originally meant to provide basic information on Canada's nuclear power industry, it has since become much more.

After all, the role of nuclear in Canada goes far beyond being a safe, clean, affordable and reliable source of energy. It has an important role to play in medicine, industry, food safety, research and innovation, and it supports the employment of some 60,000 Canadians.

Nuclear jobs are long-term, high-tech and well-paid. They include those who mine uranium, design reactors, generate electricity, and advance Canadian scientific and technological expertise.

Nuclear has a long and impressive history in Canada, and we should all be proud of the contributions that it has made and continues to make. In the fight against climate change, nuclear power has been a strategic asset, emitting zero greenhouse gases during generation. Indeed, one of the best things that we can do for our planet is include nuclear as part of the low-carbon, clean technology mix—and that's a fact!

I hope that you find the 2017 Factbook useful, and that you will refer to it often.

**John Barrett, PhD**
President and CEO
Canadian Nuclear Association

## EXECUTIVE SUMMARY

The 2017 edition of the Canadian Nuclear Factbook is packed full of up–to–date information on nuclear in Canada and around the world. Some of the key highlights include:

- There are currently 446 operable nuclear reactors worldwide, providing 11.5% of global electricity. Canada is home to 19 power reactors, which provide 16.6% of the country's electricity.
- A total of 60 reactors are under construction worldwide, primarily in emerging economies such as China and India. There are 168 reactors on order or planned, while another 345 have been proposed.
- Nuclear power generation helps reduce global $CO_2$ emissions, which hit a record high of 37 billion tonnes in 2014. By displacing fossil fuels such as coal and natural gas, nuclear prevents more $CO_2$ emissions than is generated by half the world's cars.
- Nuclear is the most efficient power source by land area. It is at least 15 times more efficient than renewable sources.
- Nuclear in Canada is a greater than $6 billion industry. It directly and indirectly supports a total of 60,000 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 deposits in the world.
- Canada pioneered one of the first nuclear power reactors, the CANDU. There are currently 46 operable CANDU and CANDU–derived reactors worldwide.
- Canada's nuclear industry is among the safest and most strictly regulated industries in the world.

## HISTORY OF NUCLEAR IN CANADA

**1941** George C. Laurence designs one of the world's first nuclear reactors at the National Research Council (NRC) in Ottawa.

**1944** The NRC builds a nuclear research facility in Chalk River, ON.

**1945** The Zero Energy Experimental Pile (ZEEP) reactor makes Canada the second country to control a nuclear fission reaction.

**1946** The Atomic Energy Control Board (AECB) is established as Canada's federal nuclear regulator.

**1947** The National Research Experimental (NRX) reactor, then the most powerful reactor in the world, comes into operation at Chalk River.

**1951** Teams led by Harold E. Johns and Roy Errington build the world's first cobalt-60 radiation therapy unit. The first external radiation cancer treatment is delivered in London, ON.

**1952** Atomic Energy of Canada Limited (AECL) is created as a federal Crown corporation.

**1952** 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.

**1954** Wilfrid B. Lewis initiates the development of the CANDU reactor in collaboration with AECL, Ontario Hydro and Canadian General Electric Company.

**1957** The National Research Universal (NRU) reactor comes into operation at Chalk River.

**1962** 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.

**1964** AECL develops the first commercial cobalt-60 sterilizer for food and medical supplies.

**1968** Douglas Point, Canada's first full-scale power reactor, comes online in Kincardine, ON, producing 220 MWe.

**1972** The first CANDU outside Canada comes online at Rajasthan-1 in India.

**1973** All four units at Pickering A come online at 2,060 MWe, making it then the largest nuclear generating station in the world.

**1982** Point Lepreau in New Brunswick and Gentilly-2 in Quebec come online at 635 MWe each.

**1994** Bertram N. Brockhouse is awarded the Nobel Prize for his neutron scattering research at Chalk River.

**1996** Two CANDU reactors are sold to China, the largest commercial contract between two countries at the time.

**2000** The Canadian Nuclear Safety Commission (CNSC) is formed under the new Nuclear and Safety Control Act, replacing the AECB as Canada's nuclear regulator.

**2002** 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.

**2011** AECL's commercial operations are acquired by Candu Energy, a wholly–owned subsidiary of SNC–Lavalin. AECL remains a federal Crown corporation.

**2012** Two units at Bruce A come back online after being refurbished, making Bruce Power the largest operating nuclear generating station in the world.

**2015** Canadian Nuclear Laboratories (CNL), a private–sector organization, is contracted to manage and operate AECL's laboratories.

**2016** SNC–Lavalin announces a joint venture with the China National Nuclear Corporation (CNNC) and Shanghai Electric Company to build Advanced Fuel CANDU Reactors (AFCR) in China and internationally.

# NUCLEAR
## POWER GLOBALLY AND IN CANADA

## NUCLEAR POWER GLOBALLY

Nuclear power is the largest non-hydro source of low-carbon, clean energy worldwide. It currently provides 11.5% of global electricity.

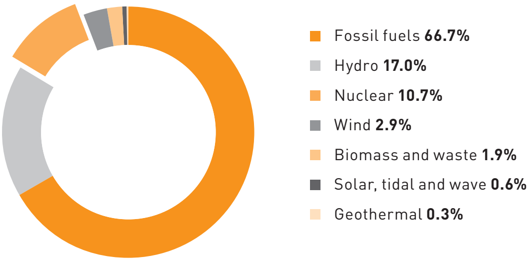
Currently, there are 446 operable reactors worldwide, with a net generating capacity of approximately 391 GWe.

- This includes 43 Japanese reactors that were taken offline shortly after the 2011 Fukushima accident. As of September 2016, seven have been reintroduced to the grid, and another 22 have applied for restarts.
- It also includes seven German reactors that were taken offline post-Fukushima. Germany plans to phase out all of its nuclear reactors by 2022.

A total of 60 reactors are under construction worldwide, primarily in emerging economies such as China and India.

There are 168 reactors on order or planned, while another 345 have been proposed.

### GLOBAL SOURCES OF ELECTRICITY IN 2013




**SOURCE** | U.S. Energy Information Administration. "International Energy Statistics." 2016, www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12.

## CURRENTLY OPERABLE NUCLEAR POWER REACTORS

| COUNTRY | UNITS | NET CAPACITY (MWe) | FUEL SHARE (%) |
|---|---|---|---|
| Argentina | 3 | 1,627 | 4.8 |
| Armenia | 1 | 376 | 34.5 |
| Belgium | 7 | 5,943 | 37.5 |
| Brazil | 2 | 1,901 | 2.8 |
| Bulgaria | 2 | 1,926 | 31.3 |
| Canada | 19 | 13,491 | 16.6 |
| China | 34 | 30,597 | 3.0 |
| Czech Republic | 6 | 3,904 | 32.5 |
| Finland | 4 | 2,741 | 33.7 |
| France | 58 | 63,130 | 76.3 |
| Germany | 8 | 10,728 | 14.1 |
| Hungary | 4 | 1,889 | 52.7 |
| India | 21 | 6,129 | 3.4 |
| Iran | 1 | 915 | 1.3 |
| Japan | 43 | 40,480 | 0.5 |
| Mexico | 2 | 1,600 | 6.8 |
| Netherlands | 1 | 485 | 3.7 |
| Pakistan | 3 | 725 | 4.4 |
| Romania | 2 | 1,310 | 17.3 |
| Russia | 36 | 27,167 | 18.6 |
| Slovakia | 4 | 1,816 | 55.9 |
| Slovenia | 1 | 696 | 38.0 |
| South Africa | 2 | 1,830 | 4.7 |
| South Korea | 25 | 23,017 | 31.7 |
| Spain | 7 | 7,121 | 20.3 |
| Sweden | 9 | 8,849 | 34.3 |
| Switzerland | 5 | 3,333 | 33.5 |
| Taiwan | 6 | 4,927 | 16.3 |
| U.K. | 15 | 8,883 | 18.9 |
| U.S. | 100 | 100,013 | 19.5 |
| Ukraine | 15 | 13,107 | 56.5 |
| **Total** | **446** | **390,656** | |

**SOURCE** | World Nuclear Association. "World Nuclear Power & Uranium Requirements." 2016, www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactors-and-uranium-requireme.aspx.

## GLOBAL NUCLEAR POWER IN CONTEXT

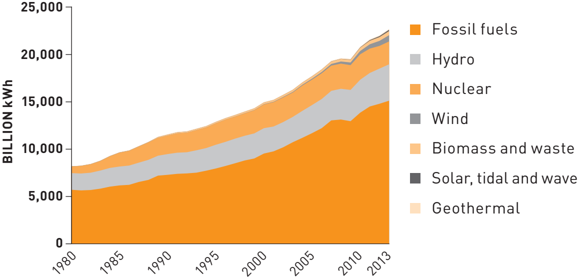
Nuclear generated 10.7% of global electricity in 2013.

Fossil fuels were the most widely used electricity source by far, at 66.7%, and also remain the fastest growing source in total power.

Hydro power continues to be the largest source of low–carbon electricity globally.

Renewable sources other than hydro, including wind, biomass, waste, solar, tidal, wave and geothermal, generated 5.7% combined.

### GLOBAL ELECTRICITY GENERATION SINCE 1980




DID YOU KNOW?

**IT IS ESTIMATED THAT IN 2030, THE WORLD WILL DEMAND NEARLY TWICE THE AMOUNT OF ELECTRICITY WE USE TODAY.**

**SOURCE** | U.S. Energy Information Administration. "International Energy Statistics." 2016, www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12.

## NUCLEAR POWER IN CANADA

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

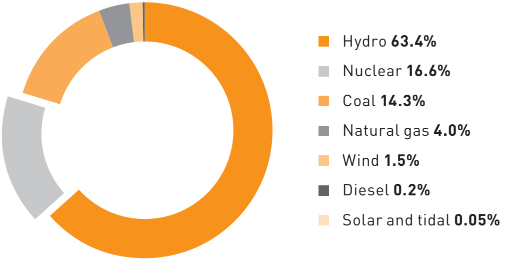
Nuclear power provided approximately 16.6% of Canada's electricity in 2015.

Hydro power is the most utilized source of electricity in Canada, generating approximately 63.4% of the electricity in 2015.

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

Wind, solar and tidal power combined to provide approximately 1.5% of Canada's electricity in 2015.

### CANADIAN SOURCES OF ELECTRICITY IN 2015




DID YOU KNOW?

**IN 2014, ONTARIO BECAME THE FIRST JURISDICTION IN NORTH AMERICA TO COMPLETELY PHASE OUT THE USE OF COAL-FIRED POWER PLANTS.**

**SOURCE** | Statistics Canada. "Electric power generation, by class of electricity producer." 2016, www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1270002.

## CANADA'S NUCLEAR POWER REACTORS

| FACILITY | STATUS | NET CAPACITY (MWe) | START YEAR |
|---|---|---|---|
| Bruce A: Unit 1 | Operable | 750 | 1977 |
| Bruce A: Unit 2 | Operable | 750 | 1977 |
| Bruce A: Unit 3 | Operable | 750 | 1978 |
| Bruce A: Unit 4 | Operable | 750 | 1979 |
| Bruce B: Unit 5 | Operable | 817 | 1985 |
| Bruce B: Unit 6 | Operable | 817 | 1984 |
| Bruce B: Unit 7 | Operable | 817 | 1986 |
| Bruce B: Unit 8 | Operable | 787 | 1987 |
| Darlington: Unit 1 | Operable | 881 | 1992 |
| Darlington: Unit 2 | Operable | 881 | 1990 |
| Darlington: Unit 3 | Operable | 881 | 1993 |
| Darlington: Unit 4 | Operable | 881 | 1993 |
| 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 | 515 | 1983 |
| Pickering B: Unit 6 | Operable | 515 | 1984 |
| Pickering B: Unit 7 | Operable | 515 | 1985 |
| Pickering B: Unit 8 | Operable | 515 | 1986 |
| Point Lepreau | Operable | 635 | 1983 |
| Gentilly-2 | Shut down | 635 | 1983 |

DID YOU KNOW?

**IN TOTAL, CANADA'S NUCLEAR FLEET PRODUCES ENOUGH ELECTRICITY TO POWER 10.5 MILLION OF CANADA'S 13.3 MILLION HOUSEHOLDS.**

## BRUCE POWER NUCLEAR GENERATING STATION

Bruce Power nuclear generating station (NGS) is 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 energy to the grid in 1977.

Currently operating at 6,238 MWe from eight reactors, Bruce Power can generate almost 55 billion kWh per year—enough electricity to power 4.9 million Canadian households. (An average Canadian household consumes about 11,100 kWh per year.)

- **6,238 MWe OUTPUT**
- **POWERS 4.9 MILLION CANADIAN HOMES**
- **FIRST POWER TO GRID IN 1977**
- **CURRENTLY THE LARGEST OPERATING NGS IN THE WORLD!**

## DARLINGTON NUCLEAR GENERATING STATION

Darlington NGS is Canada's second–largest nuclear facility. It is located on the shore of Lake Ontario, 60 km from downtown Toronto, Ontario.

Currently operating at 3,524 MWe from four reactors, Darlington NGS is capable of producing up to 31 billion kWh annually—or enough to power over 2.7 million Canadian households.

- **3,524 MWe OUTPUT**
- **POWERS 2.7 MILLION CANADIAN HOMES**
- **FIRST POWER TO GRID IN 1990**

## PICKERING NUCLEAR GENERATING STATION

When Pickering A was completed in 1973, it was the world's largest nuclear generating station. It is located 30 km from downtown Toronto, Ontario.

Now, with a combined six units at Pickering A and B producing 3,094 MWe, Pickering NGS is currently capable of producing up to 27 billion kWh per year, or enough to power 2.4 million Canadian households.

Pickering NGS had eight reactors in total until Pickering 2 and 3 were put into cold storage in 2005.

The remaining six reactors are scheduled to run until 2024, when they will be decommissioned.

- **3,094 MWe OUTPUT**
- **POWERS 2.4 MILLION CANADIAN HOMES**
- **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 33% of New Brunswick's electricity.

Point Lepreau operates at 635 MWe, producing 5.5 billion kWh per year, or enough to power 500,000 Canadian households.

- **635 MWe OUTPUT**
- **POWERS 500,000 CANADIAN HOMES**
- **FIRST POWER TO GRID IN 1983**

**SOURCE** | Statistics Canada. "Electric power generation, by class of electricity producer." 2016, www5.statcan.gc.ca/cansim/a26?lang=eng&retrLang=eng&id=1270002.

## NUCLEAR REFURBISHMENTS

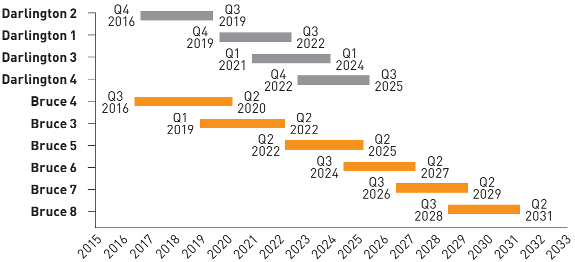
The life of a nuclear reactor can be extended for several decades through refurbishment, a process of modernizing and enhancing major equipment and systems to support long–term operation.

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 Power units 1 and 2 have already been refurbished. All three reactors returned to service in 2012.

According to a study by the Conference Board of Canada, the economic benefits of refurbishing the four Darlington reactors and the 30+ years of operation following the project will total $89.9 billion.

### NUCLEAR REFURBISHMENT SEQUENCE




***** The sequence is currently being revised to reflect scheduling adjustments.

**SOURCE** | Ontario Ministry of Energy. "Nuclear Refurbishment Sequence." 2015, http://www.energy.gov.on.ca/en/ltep/achieving-balance-ontarios-long-term-energy-plan/ltep-fig14/.

The Conference Board of Canada. "Continued Operation of the Darlington Nuclear Generating Station: An Impact Analysis on Ontario's Economy." 2016, pp. 12.

# NUCLEAR
## AND THE ENVIRONMENT

## NUCLEAR AND THE ENVIRONMENT

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

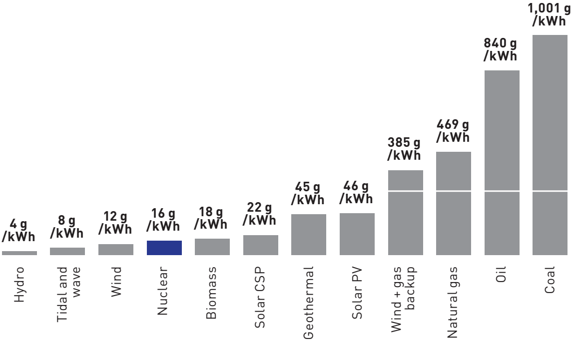
When considering the entire power generation life cycle, including construction, mining, operation and decommissioning, nuclear comes out as one of the cleanest technologies available.

### WHY NOT RENEWABLES ALONE?

A grid powered entirely on intermittent sources such as wind would rely on backup sources about 80% of the time.

Backup most often comes from natural gas, which increases $CO_2$ emissions greatly.

### $CO_2$ EMISSIONS BY ENERGY SOURCE




**SOURCE** | Intergovernmental Panel on Climate Change. "Renewable Energy Sources and Climate Change Mitigation." 2011, pp. 19.

## WHAT LOW–CARBON MEANS

Nuclear, wind, solar and hydro are considered low–carbon sources of electricity because they produce virtually zero carbon and other GHG emissions during generation.

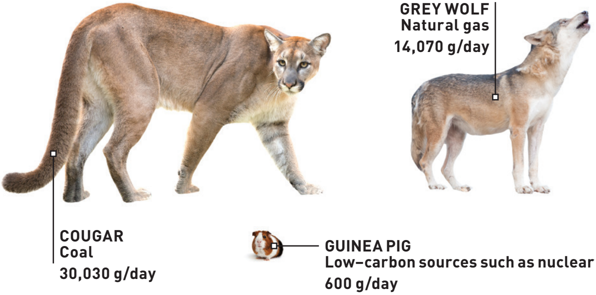
All low–carbon sources of electricity depend on fossil fuels to some degree (e.g., during construction or as backup power).

When the entire power generation life cycle is taken into account, it is possible to calculate how much $CO_2$ is emitted for each unit of electricity generated.

## HOW MUCH $CO_2$ YOU GENERATE

As the average Canadian household consumes approximately 30 kWh of electricity each day, using electricity from low–carbon sources greatly reduces the impact of home activities on the climate.

## $CO_2$ RELEASED DAILY PER CANADIAN HOUSEHOLD BY SOURCE




**SOURCE** | Statistics Canada. "Households and the Environment: Energy Use." 2015, www.statcan.gc.ca/pub/11-526-s/2013002/part-partie1-eng.htm.

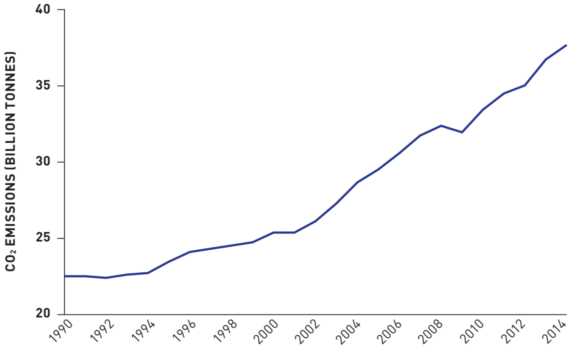
## HISTORICAL $CO_2$ EMISSION TRENDS

Global $CO_2$ emissions reached a record high of 37 billion tonnes in 2014.

If we replaced all the world's coal and natural gas plants with low–carbon nuclear, we would reduce global $CO_2$ emissions by 22.2%.

Today, by displacing the use of coal and natural gas, nuclear power helps avoid about 2.5 billion tonnes of $CO_2$ emissions annually. That's the same as taking about 520,000,000 cars off the road—or over half of all the cars in the world!

### GLOBAL $CO_2$ EMISSIONS SINCE 1990




DID YOU KNOW?

**REPLACING COAL AND NATURAL GAS WITH NUCLEAR WOULD TURN BACK THE CLIMATE CLOCK OVER A DECADE!**

**SOURCE** | European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. "Trends in Global $CO_2$ Emissions: 2015 Report." 2015, pp. 28-29.

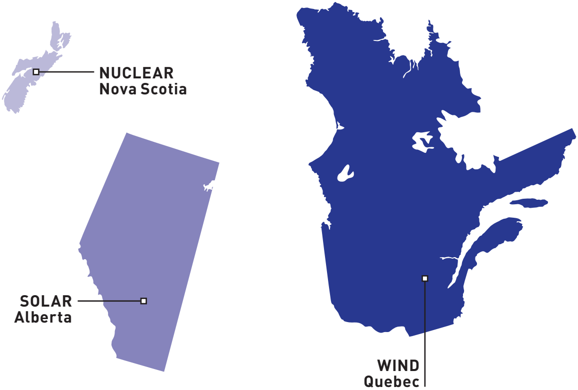
## NUCLEAR'S LAND FOOTPRINT

Nuclear is the most land-efficient means of electricity production, generating 47.6 MWe/km$^2$, including all aspects of production such as mining and fuel fabrication.

Other low-carbon options, such as solar and wind, produce far less power per unit area at 3.1 MWe/km$^2$ and 1.6 MWe/km$^2$, respectively.

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

### LAND USE REQUIRED TO SUPPLY GLOBAL ELECTRICITY




**SOURCE** | McDonald, Robert, et al. "Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for the United States of America." PLoS ONE. 2009.

# 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.

Similar to 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 "fissioned"). Fission splits the U-235 into smaller fragments and releases 100 million times more energy than splitting a chemical bond during combustion.

URANIUM ORE

**DID YOU KNOW?**

**CANDU REACTORS USE U-235 IN ITS NATURAL CONCENTRATION, WHEREAS OTHER REACTOR DESIGNS USE U-235 ENRICHED TO ABOUT 3% OR HIGHER.**

## CONVERTING URANIUM INTO FUEL FOR CANDU REACTORS

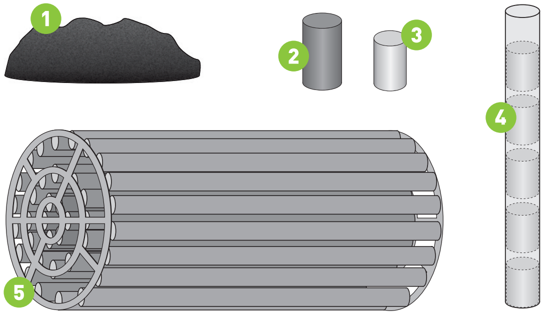
**Mining** Uranium ore is extracted from the ground in one of three ways: open–pit mining, underground mining or in–situ recovery.

**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 other minerals, and 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 for use in CANDU reactors.

**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.

**UNDERGROUND TUNNEL AT CIGAR LAKE MINE**

**PHOTO** | Cameco

## CANADA'S URANIUM INDUSTRY

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

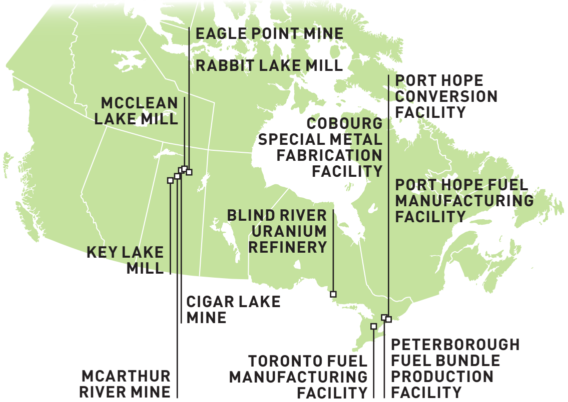
Canada has the world's highest grade uranium deposits with concentrations more than 100 times the global average.

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 (GE Hitachi Nuclear Energy Canada), Ontario.

### MAP OF CANADIAN URANIUM FACILITIES



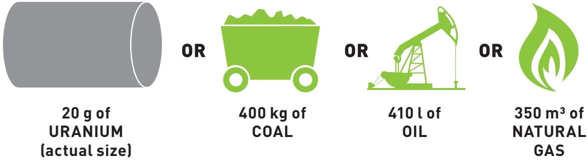
## URANIUM AS NUCLEAR FUEL

Nuclear fission is a very efficient source of energy, so a nuclear reactor requires very little fuel.

Uranium pellets are approximately 20 grams each, and less than ten are needed to power the average Canadian household for a year.

To provide the same amount of electricity as one 20 gram uranium pellet, one would have to burn 400 kilograms of coal or 410 litres of oil or 350 cubic metres of natural gas.

### FUEL REQUIRED TO PRODUCE THE SAME AMOUNT OF ELECTRICITY




**CANDU FUEL BUNDLE**

**PHOTO** | Nuclear Waste Management Organization

## HOW FISSION WORKS

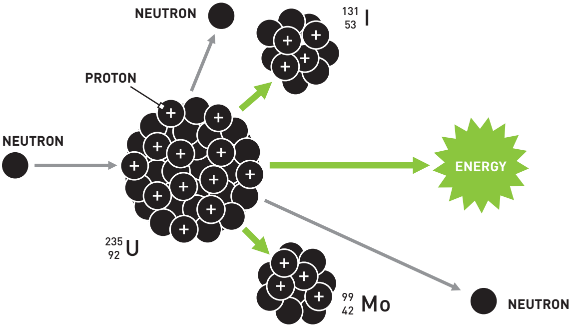
Uranium, in both of its main isotopes, U-235 and U-238, is relatively stable before entering the reactor, meaning it does not emit very much radiation—so little that unused fuel bundles are safe to handle.

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

These neutrons collide with other nearby U-235 atoms and allow the effect to continue, similar to how heat from a candle wick allows it to continue burning. 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 turning an electrical generator. The heat used to generate the steam comes from the energy produced from the fission reaction.

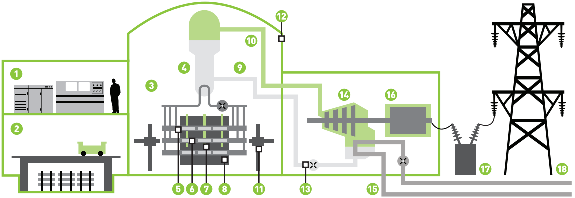
The basic parts of a nuclear reactor are the uranium fuel, the moderator and the coolant.

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, it can cause further fission.

A 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

## CANDU REACTORS

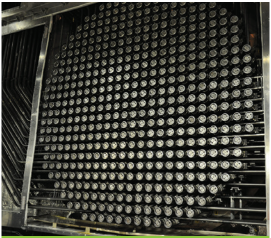
CANDU stands for CANada Deuterium Uranium, because it was invented in Canada, uses deuterium oxide (also known as "heavy water") as a moderator and coolant, and uses uranium as a fuel.

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

Since natural uranium does not require enrichment, fuel costs for CANDU reactors are very low.

CANDU reactors can be refuelled while operating at full power, while most other designs must 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 system while the reactor is operating under full power.



**CANDU REACTOR FACE AT BRUCE A**

**PHOTO** | Bruce Power

**DID YOU KNOW?**

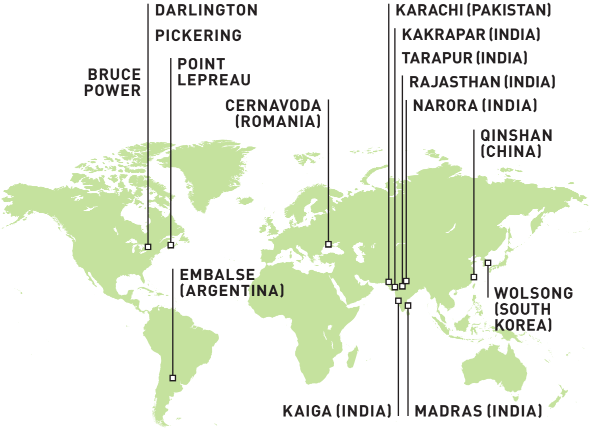
**ONE CANDU REACTOR CAN BE POWERED WITH THE RECYCLED URANIUM FROM FOUR LIGHT WATER REACTORS WITHOUT ANY ADDITIONAL FUEL.**

## COUNTRIES USING CANDU REACTORS

Canada has exported CANDU reactors to Argentina, China, India, Pakistan, Romania and South Korea. In total, there are 34 CANDU reactors globally, 30 of which are currently operable.

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

### MAP OF CANDU REACTORS



## CANDU AND CANDU-DERIVED REACTORS IN USE GLOBALLY

| FACILITY | UNITS | STATUS | NET CAPACITY (MWe) |
|---|---|---|---|
| Bruce Power | 8 CANDU reactors | Operable | 6,238 |
| Darlington | 4 CANDU reactors | Operable | 3,524 |
| Pickering | 6 CANDU reactors | Operable | 3,094 |
| | 2 CANDU reactors | Shut down | 1,030 |
| Point Lepreau | 1 CANDU reactor | Operable | 635 |
| Gentilly-2 | 1 CANDU reactor | Shut down | 635 |
| Cernavoda (Romania) | 2 CANDU reactors | Operable | 1,305 |
| Embalse (Argentina) | 1 CANDU reactor | Operable | 600 |
| Karachi (Pakistan) | 1 CANDU reactor | Operable | 125 |
| Kaiga (India) | 4 CANDU-derived reactors | Operable | 808 |
| Kakrapar (India) | 2 CANDU-derived reactors | Operable | 404 |
| Madras (India) | 2 CANDU-derived reactors | Operable | 357 |
| Narora (India) | 2 CANDU-derived reactor | Operable | 404 |
| Rajasthan (India) | 1 CANDU reactor | Operable | 187 |
| | 1 CANDU reactor | Shut down | 90 |
| | 4 CANDU-derived reactors | Operable | 808 |
| Tarapur (India) | 2 CANDU-derived reactors | Operable | 980 |
| Qinshan (China) | 2 CANDU reactors | Operable | 1,280 |
| Wolsong (South Korea) | 4 CANDU reactors | Operable | 2,579 |

DID YOU KNOW?

**ELECTRICITY SUPPLY IN CHINA HAS GROWN BY OVER FOUR TIMES SINCE 2000. THAT'S LIKE ADDING SIX NEW CANADAS TO THE GLOBE!**

## POWER REACTOR DESIGNS IN USE GLOBALLY

CANDU reactors 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 290 of the world's 446 currently operable nuclear power reactors.

### DIFFERENCES AMONG POWER REACTOR DESIGNS

| REACTOR DESIGN | FUEL | MODERATOR | COOLANT | NUMBER |
|---|---|---|---|---|
| Pressurized water reactor (PWR) | Enriched $UO_2$ | Water | Water | 290 |
| Boiling water reactor (BWR) | Enriched $UO_2$ | Water | Water | 78 |
| Pressurized heavy water reactor (PHWR) | Natural $UO_2$ | Heavy water | Heavy water | 46 |
| Light water graphite reactor (LWGR) | Enriched $UO_2$ | Graphite | Water | 15 |
| Gas-cooled reactor (GCR) | Natural U, enriched $UO_2$ | Graphite | Carbon dioxide | 14 |
| Fast breeder reactor (FBR) | $PuO_2$ and $UO_2$ | None | Liquid sodium | 3 |

DID YOU KNOW?

**PRESSURIZED WATER REACTORS MAKE UP APPROXIMATELY TWO-THIRDS OF THE POWER REACTORS IN USE TODAY. THEY ARE MOST COMMON IN THE U.S., FRANCE, JAPAN, RUSSIA AND CHINA.**

**SOURCE** | World Nuclear Association. "Nuclear Power Reactors." 2016, www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx.

## SMALL MODULAR REACTORS

Small modular reactors (SMRs) are modern reactors designed to be built economically in factory–like conditions (rather than fully constructed onsite), with capacities ranging from approximately 10 MWe to 300 MWe.

The potential applications for SMRs in Canada include providing electricity to smaller and/or remote communities and providing process heat for resource industries such as Ontario's Ring of Fire mining or Alberta's oil sands.

The deployment of SMRs in Canada would reduce greenhouse gas emissions drastically since nuclear would, in many cases, replace diesel generation.

SMRs could also have a positive socio–economic impact on Canada depending on the country's participation in developing and manufacturing the technology.

Currently there are more than 45 SMR designs under development, including four already under construction in Argentina, Russia and China.

**WESTINGHOUSE SMR SCHEMATIC**

**PHOTO** | Westinghouse Electric Company LLC.

**SOURCE** | International Atomic Energy Agency. "Small and Medium Sized Reactors (SMRs) Development, Assessment and Deployment." 2014, www.iaea.org/NuclearPower/SMR/.
Hatch. "Ontario Ministry of Energy – SMR Deployment Feasibility Study." 2016, pp. 6.

# 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:

**Low–level waste** (LLW) 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 is LLW.

**Intermediate–level waste** (ILW) includes items that have had more direct contact with radioactive substances such as ion–exchange resins and reactor components.

**High–level waste** (HLW) is used fuel. It is generated at nuclear power plants and is highly radioactive.

**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.

### RADIOACTIVE WASTE IN CANADA

| WASTE CATEGORY | INVENTORY TO END OF 2013 |
|---|---|
| Low–level waste | 2,352,672 $m^3$ |
| Intermediate–level waste | 34,770 $m^3$ |
| High–level waste (used nuclear fuel) | 10,021 $m^3$ |
| Waste rock | 179,000,000 tonnes |
| Mill tailings | 216,000,000 tonnes |

**SOURCE** | Canadian Nuclear Laboratories, Low-Level Radioactive Waste Management Office. "2013 Inventory Summary Report." 2015, pp. 3.

## USED NUCLEAR FUEL

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

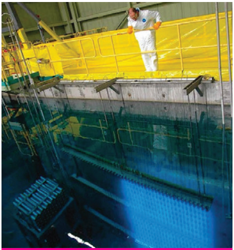
Nuclear fuel bundles are removed from reactors when the concentration of the uranium-235 inside becomes too low to sustain the fission reaction at the desired power level.

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 a year, nuclear fuel bundles emit less than 0.1% of the heat generated in 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**

**PHOTO** | Bruce Power

**DID YOU KNOW?**

**ONLY ABOUT 1% OF THE TOTAL ENERGY IN THE URANIUM IS USED BEFORE THE BUNDLES ARE REMOVED FROM THE REACTOR. USED FUEL MAY BE RECYCLED TO BECOME USABLE AGAIN, AS IS DONE IN SOME COUNTRIES. THAT'S WHY SCIENTISTS PREFER NOT TO REFER TO IT 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 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**

**DID YOU KNOW?**

**NUCLEAR PRODUCES VERY LITTLE WASTE. SO LITTLE, IN FACT, THAT IF ALL THE POWER YOU EVER USED CAME FROM NUCLEAR, YOUR LIFETIME WASTE WOULD FIT IN A SODA CAN.**

**PHOTO** | Ontario Power Generation

## NUCLEAR WASTE MANAGEMENT ORGANIZATION

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

In 2007, the Government of Canada accepted the NWMO's recommendation for Adaptive Phased Management (APM), now being implemented by the NWMO.

The end point of APM is the centralized containment and isolation of used nuclear fuel in a suitable rock formation.

The process for selecting a site for a deep geological repository (DGR) has been designed to ensure, above all, that the site chosen is safe and secure.

The site will be located in an area with an informed and willing host.

The goal will be reached through steps and decision points that can be adapted as required:

- Citizens will be involved throughout implementation and have the opportunity to provide input.
- The plan requires that the used fuel be retrievable throughout implementation.

APM includes the provision of financial surety—as required by law—and long-term program funding to ensure sufficient funds will be available for the long-term care of the used fuel.

**DID YOU KNOW?**

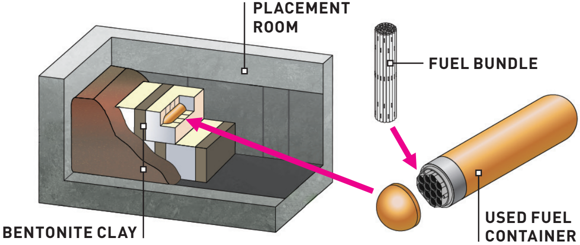
**THE MANAGEMENT OF FUTURE NUCLEAR WASTE IS ALREADY PAID FOR AS IT IS GENERATED. PRODUCERS OF USED FUEL ARE REQUIRED BY THE NUCLEAR FUEL WASTE ACT TO CONTRIBUTE TO TRUST FUNDS THAT ENSURE THE LONG-TERM MANAGEMENT OF CANADA'S USED NUCLEAR FUEL.**

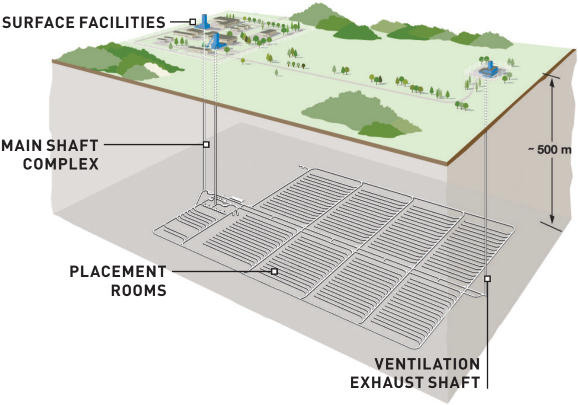
## DEEP GEOLOGICAL REPOSITORY

Used nuclear fuel stored in a DGR will be placed in secure containers 500 metres underground.

Advanced containers and secure geology will ensure there is no radiation exposure to the public or environment.

### DGR SCHEMATIC



## TRANSPORTATION

Every year around the world, about 10 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.

Some of the 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
- Careful study and analysis of incidents

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

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

**DID YOU KNOW?**

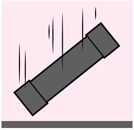
**ONLY 3% OF RADIOACTIVE SHIPMENTS ARE FUEL CYCLE RELATED. THE REST RELATE TO SUCH FIELDS AS MEDICINE, RESEARCH, AGRICULTURE, MANUFACTURING AND NON–DESTRUCTIVE TESTING.**

## TYPES OF PACKAGES

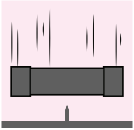
For the packaging of radioactive substances, Canada has adopted the standards of the International Atomic Energy Agency (IAEA), which are based on the characteristics of the material they contain.

- Ordinary industrial containers 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 used nuclear fuel and highly radioactive waste. These packages undergo stringent testing, including free drop testing, puncture testing, thermal testing and immersion testing.

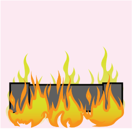
### TYPE B PACKAGE TESTS



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



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



**THERMAL**
A 30-minute, fully-engulfing fire at 800 °C (1475 °F)

**IMMERSION**
An 8-hour immersion under water

# NUCLEAR
## SCIENCE & TECHNOLOGY

## NUCLEAR SCIENCE & TECHNOLOGY

Nuclear science and technology (S&T) is an integral part of our national manufacturing and engineering capability. That is why the Government of Canada and Canada's nuclear industry have a long history of investing in nuclear S&T.

Research initiatives at national laboratories, universities and research reactors across the country support affordable electricity, product improvements, medical services, training and other activities.

Canada is a historic leader in nuclear research, and is home to four Nobel prizes related to nuclear S&T:

- **Ernest Rutherford** in 1908 for his work at McGill 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.
- **Arthur B. McDonald** in 2015 for the discovery of neutrino oscillations, showing that neutrinos have mass.

Nuclear technology plays an important role in almost every technical field across Canada, including:

- Advanced electronics and material development
- Aerospace and automotive technology
- Earth science and archaeology
- Environmental technology
- Food processing
- Mining and natural resources
- Nuclear medicine
- Pharmaceutical and medical devices

## NUCLEAR MEDICINE

One of the most familiar applications of nuclear technology is the use of radioactive substances (called radioisotopes) for the diagnosis of various diseases and the treatment of certain cancers.

Over 40 million nuclear medicine procedures are performed annually.

Radioisotopes are produced in nuclear reactors and cyclotrons.

### HOW NUCLEAR MEDICINE WORKS

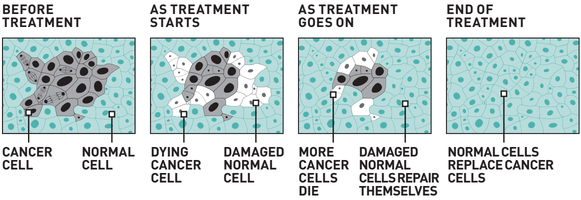
#### Diagnosis

Radioisotopes injected into the patient collect in important tissues, such as organs or a tumor, and emit radiation which is picked up by a detector outside the body to help produce a diagnosis.

#### Treatment

Radioisotopes injected into the patient collect in the tumor and emit radiation into it, destroying the cancerous cells, and allowing the healthy tissue to heal.

### SUCCESSFUL CANCER TREATMENT



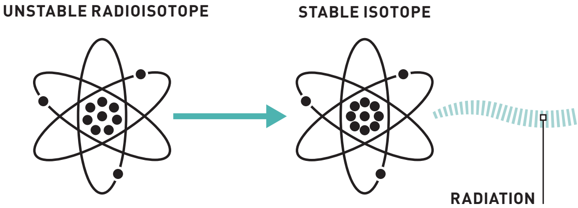
## RADIOISOTOPES

Atoms exist in several different forms of themselves called isotopes, some of which have either too few or too many neutrons.

In some cases, this neutron imbalance causes the atoms to be unstable, and they will undergo a change (or “decay”) to become stable, emitting radiation while doing so. These are called radioisotopes.

Some radioisotopes decay faster than others. The shorter the half–life, the faster they decay.

### NUCLEAR DECAY




### RADIOISOTOPES COMMONLY USED IN MEDICINE

| RADIOISOTOPE | HALF–LIFE | COMMON USES |
|---|---|---|
| Cobalt-60 | 5.27 years | Treatment of cancers, delivered from outside the body |
| Fluorine-18 | 109.77 minutes | Diagnosis of cancers in PET scans when incorporated as fludesoxyglucose (FDG) |
| Iodine-131 | 8.02 days | Diagnosis and treatment of thyroid disorders and cancers |
| Technetium-99m | 6.0058 hours | Diagnosis of heart and bone disorders, brain tumors and other cancers |

## INDUSTRIAL APPLICATIONS OF NUCLEAR S&T

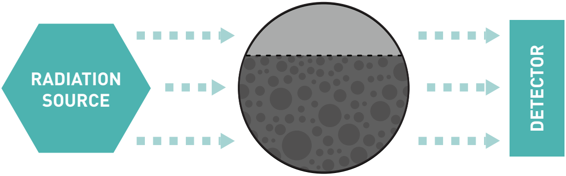
Nuclear technology offers various techniques used in industry to ensure the integrity of important mechanical components without damaging them. This is a form of non–destructive testing.

High–power neutrons can penetrate solid steel to a depth of about half a metre to image thick pipes and even entire engines, or simulate their response to stress. This type of testing is critical to ensure the safety of many common items.

Nuclear imaging can also be used in a gauge, for example, to detect how full a pipe or canister is.


HUMBOLDT NUCLEAR DENSITY GAUGE

### NUCLEAR DENSITY GAUGE SCHEMATIC



## APPLICATIONS OF NUCLEAR IMAGING

### Aerospace

Used to study the structural integrity of critical aircraft components such as rotors, wings and landing gear to reduce their chance of in–flight failure.

### Automotive

Makes it possible to examine the molecular structure of engines so that the manufacturing process can be improved to reduce defects and improve reliability.

### Medical devices

Makes it possible to detect and improve the surface structure of medical implants such as pacemakers to increase their compatibility with the human body.

### Natural resources

Enhances the analysis of pipes and other oil and gas components to decrease defects and improve the industry's environmental and human health performance.

### Pharmaceuticals

Makes it possible to develop sophisticated delivery systems for pharmaceuticals that can reduce side effects and improve effectiveness.

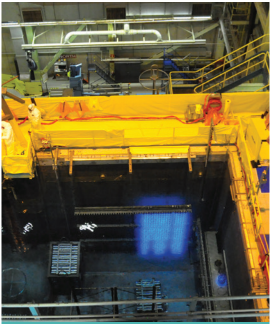
## AGRICULTURE, FOOD AND HEALTH

Radiation from nuclear sources is also widely used to sterilize much of the food and products we consume today.

Gamma rays from powerful sources are used to kill bacteria and other pathogens while leaving the product safe and unchanged.

Cobalt-60 is the primary source used for sterilization. It is also used for radiation therapy treatments, although this use is being gradually replaced by linear accelerators.

Cobalt-60 is manufactured by exposing "pencils" of cobalt-59—the non–radioactive isotope of cobalt—to high doses of neutron radiation inside a nuclear reactor.



**COBALT-60 PRODUCTION**

**DID YOU KNOW?**

**ALMOST ALL OF GLOBAL COBALT-60 SUPPLY IS PRODUCED BY CANDU REACTORS, INCLUDING THOSE AT THE PICKERING AND BRUCE POWER NUCLEAR GENERATING STATIONS.**

**PHOTO** | Bruce Power

## APPLICATIONS OF STERILIZATION WITH RADIATION

### Agriculture

Induces genetic changes that increase crop yield and pest–resistance. This technique has saved hundreds of millions of lives in South America, Asia and Africa.

### Cancer treatment

Used to treat cancer since cancer cells are more sensitive to radiation than healthy cells. Cobalt-60 treatment units are among the most common technologies for external beam radiation therapy worldwide.

### Food

Eliminates dangerous pathogens, including bacteria, viruses, fungi and insects to reduce food poisoning and delay spoilage.

### Health and beauty supplies

Used to sterilize a range of cosmetics, contact lenses and other personal items.

### Medical supplies

Ensures the sterility of surgical tools and single–use medical supplies such as syringes, gloves, tubes and sutures.

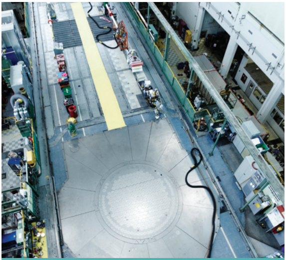
## NUCLEAR RESEARCH CENTRES

Nuclear research centres are key facilities for promoting nuclear S&T.

There are twelve major nuclear research centres in Canada. Seven of them use research reactors and five are based on cyclotron technology.

Canada's largest nuclear research centre is Chalk River Laboratories (CRL), owned by Atomic Energy of Canada Limited (AECL) and operated by Canadian Nuclear Laboratories (CNL).

- CRL boasts several nuclear facilities, such as the National Research Universal (NRU) reactor and the ZED-2 reactor, as well as multiple other facilities and laboratories that support innovation in safety, security, health, the environment and clean energy.
- The NRU is Canada's most powerful research reactor, and the third most powerful research reactor in the world. Among other things, it generates neutrons for materials testing, and produces radioisotopes for the diagnosis and treatment of diseases.

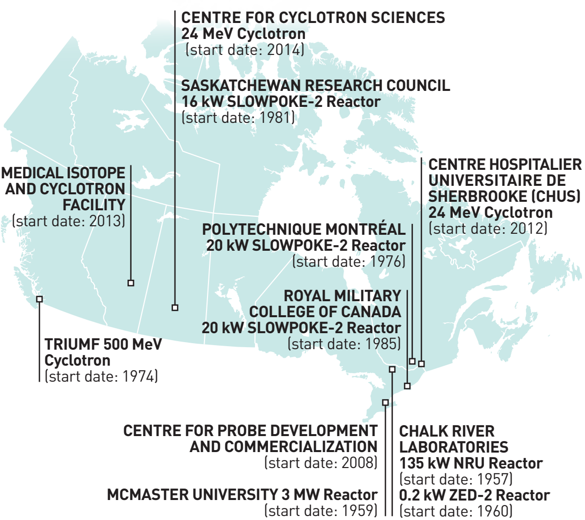


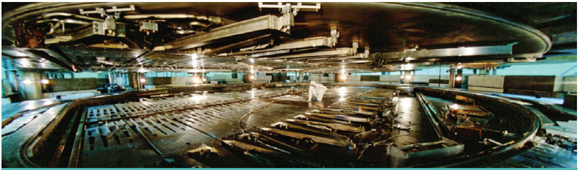
NRU REACTOR

TRIUMF operates the world's most powerful cyclotron, enabling leading research in atomic physics as well as new methods of producing radioisotopes.

PHOTO | Canadian Nuclear Laboratories

## MAP OF NUCLEAR RESEARCH CENTRES



INSIDE THE TRIUMF CYCLOTRON

**PHOTO** | TRIUMF

## FUSION RESEARCH

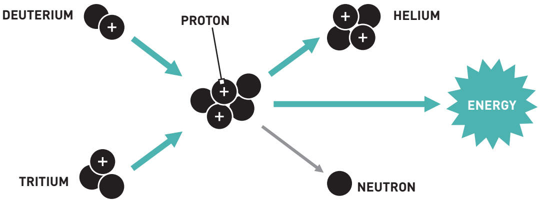
Fusion is a form of nuclear energy with the potential to create massive amounts of heat by forcing atomic nuclei together. It is essentially the opposite of fission, which involves splitting atoms apart.

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 relatively clean operation and short-lived radioactive waste.

### NUCLEAR FUSION




DID YOU KNOW?

**FUSION RESEARCH HAS BEEN UNDERWAY FOR MANY DECADES, WITH A LOT OF EXCITING PROGRESS IN RECENT YEARS, INCLUDING AT CANADIAN INSTITUTIONS. ONCE COMMERCIALIZED, THIS TECHNOLOGY HOLDS THE POTENTIAL TO REVOLUTIONIZE THE EFFICIENCY WITH WHICH HUMANITY IS CAPABLE OF GENERATING ELECTRICITY, FAR BEYOND EVEN WHAT FISSION HAS ALREADY ACHIEVED.**

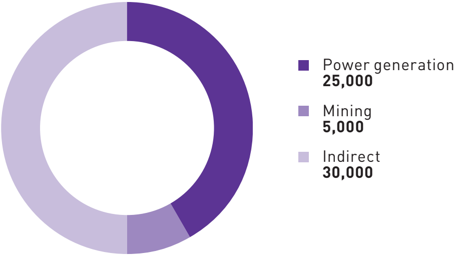
# NUCLEAR
## AND THE ECONOMY

Nuclear technology is an integral part of any advanced economy. It supports medicine, materials science, advanced manufacturing, food safety and energy production.

Nuclear in Canada is a greater than $6 billion industry with reliable well–paid employment.

Nuclear power generation directly and indirectly supports a total of 60,000 Canadian jobs.

## JOBS SUPPORTED BY NUCLEAR IN CANADA




## CLEAN GDP GROWTH

Countries with quickly growing economies, such as China, India and Brazil, depend on rapid expansion in base load electrical generation.

Nuclear and coal tend to be the most popular power options in these growth scenarios, and the choice between them has huge environmental implications.

**SOURCE** | Canadian Manufacturers & Exporters. "Nuclear: A Canadian Strategy for Energy, Jobs, and Innovation." 2012, pp. 7.

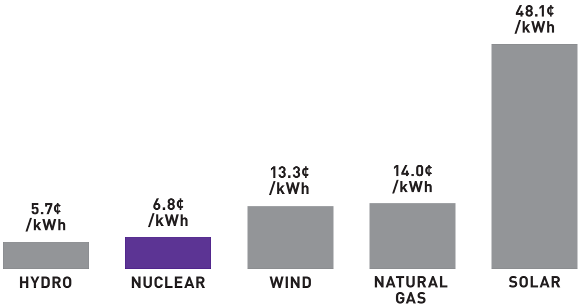
## COST OF NUCLEAR POWER

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 does. Gas and wind are about twice as expensive as nuclear, and solar is more than seven times as expensive.

### COST BY ENERGY SOURCE IN ONTARIO IN 2016




**DID YOU KNOW?**

**ABOUT 60% OF THE COST OF NUCLEAR IS ATTRIBUTABLE TO FACILITY CONSTRUCTION. ONCE BUILT, NUCLEAR HAS TREMENDOUSLY LOW FUEL AND MAINTENANCE PRICES, PROVIDING STABLE ELECTRICITY PRICES DURING THE PLANT'S LIFETIME OF UP TO 60 YEARS OR MORE.**

**SOURCE** | Ontario Energy Board. "Regulated Price Plan: Price Report." 2016, pp. 20.

## URANIUM AND THE CANADIAN ECONOMY

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

Uranium mining and fuel processing in Canada generates over $700 million annually in salaries and benefits to contractors and employers.

Uranium exports add $1.2 billion to the Canadian economy.

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

### GLOBAL URANIUM MINE PRODUCTION IN 2015

| COUNTRY | TONNES U | % OF GLOBAL |
|---|---|---|
| Kazakhstan | 23,800 | 39% |
| Canada | 13,325 | 22% |
| Australia | 5,654 | 9% |
| Niger | 4,116 | 7% |
| Russia | 3,055 | 5% |
| Namibia | 2,993 | 5% |
| Uzbekistan | 2,385 | 4% |
| China | 1,616 | 3% |
| U.S. | 1,256 | 2% |
| Ukraine | 1,200 | 2% |

DID YOU KNOW?

**MORE URANIUM HAS BEEN MINED IN CANADA THAN ANY OTHER COUNTRY—NEARLY 500,000 TONNES, OR ONE–FIFTH OF THE WORLD TOTAL.**

**SOURCE** | World Nuclear Association. "World Uranium Mining Production." 2016, www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/world-uranium-mining-production.aspx.

# RADIATION

## NUCLEAR SAFETY AND REGULATION

## RADIATION

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

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

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

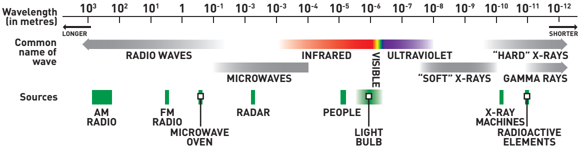
## IONIZING RADIATION

Ionizing radiation is released when atoms decay, as they do during fission reactions in a nuclear reactor. Ionizing radiation is a highly energetic type of radiation that can detach electrons from atoms.

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 and beta particles and gamma rays.

## THE ELECTROMAGNETIC SPECTRUM




* X–rays and gamma rays come from man–made devices (x–rays) or from radioactive elements (gamma rays). X–rays can have energies in the indicated gamma range, but tend not to except in high–power radiation therapy treatments.

## HOW RADIATION IS MEASURED

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).

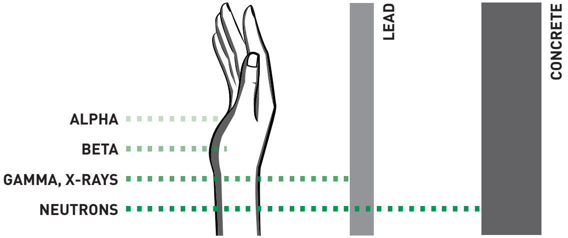
### EFFECTS OF IONIZING RADIATION

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 measureable health effects in humans.

### IONIZING RADIATION SHIELDS



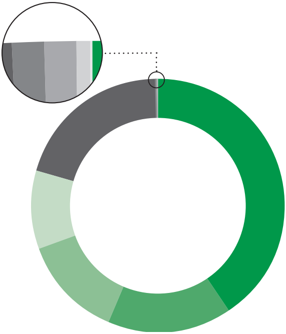
## NATURAL BACKGROUND RADIATION

While natural background radiation worldwide is on average 2.4 mSv/year, local variations can be significant. In some places, such as Ramsar, Iran, natural radiation levels can reach 260 mSv/year—thirteen times more than allowed for workers in Canadian nuclear facilities.

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 naturally occurring radon gas.

Radiation from nuclear power reactors generally adds less than 0.1% to the background radiation around nuclear facilities in Canada.

### GLOBAL RADIATION SOURCES



**NATURAL**

- Inhalation (mostly radon) **42%**
- Terrestrial **16%**
- Cosmic **13%**
- Ingestion **10%**

**ARTIFICIAL**

- Medical **20%**
- Atmospheric testing **0.16%**
- Occupational exposure **0.16%**
- Reactor accidents **0.07%**
- Nuclear fuel cycle **0.01%**

**SOURCE** | Canadian Nuclear Safety Commission. "Natural Background Radiation." 2013, nuclearsafety.gc.ca/eng/resources/fact-sheets/natural-background-radiation.cfm.

United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation: UNSCEAR 2008 Report. 2010, pp. 4.

## RADIATION EFFECTS ON THE BODY

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

Doses at these magnitudes occur only in extreme circumstances, such as in the case of emergency workers at Chernobyl. No event producing doses of this magnitude has ever occurred in Canada.

## RADIATION DOSES AND EFFECTS

| mSv | EFFECT |
|---|---|
| 10,000 | Fatal within weeks |
| 6,000 | Average dose to Chernobyl emergency workers who died within a month |
| 5,000 | Single dose which would kill half of those exposed to it within a month |
| 1,000 | Single dose which would cause radiation sickness, nausea, but not death |
| 400 | Maximum hourly radiation levels recorded at Fukushima on March 14, 2011 |
| 350 | Exposure of Chernobyl residents who were relocated |
| 100 | Lowest level linked to increased cancer risk |
| 10 | Full-body CT scan |
| 2.4 | Natural radiation to which we are all exposed, per year |
| 0.1 | Chest x-ray |
| 0.01 | Dental x-ray |
| 0.001 | Annual public dose due to nuclear power reactors in Canada |

**DID YOU KNOW?**

**WE RECEIVE OVER 100 TIMES MORE RADIATION NATURALLY THROUGH THE FOOD WE EAT THAN FROM CANADA'S NUCLEAR POWER PLANTS.**

## NUCLEAR SAFETY AND REGULATION

Canada's nuclear power program has an exemplary safety track record with over 50 years of occupational and public health and safety, and is a leader in the industry worldwide.

There are many layers of protection between nuclear operations and employees, 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 risks 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 international and national level, nuclear power generation is one of the safest energy technologies.

**IAEA DIRECTOR GENERAL YUKIYA AMANO**

**DID YOU KNOW?**

**NUCLEAR POWER TECHNOLOGY HAS THE LOWEST RATE OF FATALITIES AND INJURIES PER UNIT OF GENERATED ELECTRICITY.**

## NUCLEAR SAFETY AND REGULATION

The Canadian Nuclear Safety Commission (CNSC) is an independent regulatory 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 on individuals and organizations.

Canada's nuclear industry is among the most highly monitored and regulated industries in the world.

### THE CNSC'S MANDATE

The CNSC is mandated to monitor and regulate the use of nuclear energy and materials to protect the health, safety, and security of Canadians and the environment.

The CNSC monitors and regulates the entire 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 nuclear substances processing facilities.

**CNSC INSPECTION AT A NUCLEAR GENERATING STATION**

**PHOTO** | Canadian Nuclear Safety Commission

## WHAT THE CNSC DOES

Any person or organization that wants to possess, use, transport, or store nuclear material; or build, operate, decommission, or abandon a nuclear facility—including a nuclear power facility—must first obtain a license 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. International peer reviews and shared practices are frequently conducted through the International Atomic Energy Agency and the World Association of Nuclear Operators (WANO).

The CNSC is currently assessing proposed new nuclear projects, including a deep geological repository for nuclear waste at the Bruce site, a near-surface disposal facility at Chalk River Laboratories, the in-situ decommissioning of the Nuclear Power Demonstration reactor in Rolphton, Ontario, and the in-situ decommissioning of the WR-1 reactor at Whiteshell Laboratories in Pinawa, Manitoba.

The CNSC also works collaboratively with the federal government's Major Projects Management Office under Natural Resources Canada in regulating these major resource projects.

DID YOU KNOW?

**CNSC STAFF ARE LOCATED ONSITE AT EVERY CANADIAN NUCLEAR GENERATING STATION.**

# RESOURCES

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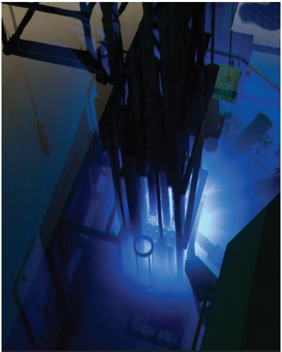
## CANADIAN UNIVERSITIES WITH NUCLEAR RESEARCH PROGRAMS

| | |
|---|---|
| Algonquin College | **www.algonquincollege.com** |
| Carleton University | **www.carleton.ca** |
| McMaster University | **www.mcmaster.ca** |
| Polytechnique Montréal | **www.polymtl.ca** |
| Queen's University | **www.queensu.ca** |
| Royal Military College of Canada | **www.rmc.ca** |
| University of Guelph | **www.uoguelph.ca** |
| University of New Brunswick | **www.unb.ca** |
| University of Ontario Institute of Technology | **www.uoit.ca** |
| University of Saskatchewan | **www.usask.ca** |
| University of Toronto | **www.utoronto.ca** |
| University of Waterloo | **www.uwaterloo.ca** |
| University of Western Ontario | **www.uwo.ca** |
| University of Windsor | **www.uwindsor.ca** |



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**DID YOU KNOW?**

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

**PHOTO** | McMaster University

## OTHER RESOURCES

| | |
|---|---|
| AREVA Canada | **www.arevacanada.ca** |
| Bruce Power | **www.brucepower.com** |
| Cameco | **www.cameco.com** |
| Canadian Nuclear Laboratories | **www.cnl.ca** |
| Canadian Nuclear Safety Commission | **www.nuclearsafety.gc.ca** |
| Canadian Nuclear Society | **www.cns-snc.ca** |
| Candian Nuclear Workers Council | **www.cnwc-cctn.ca** |
| Candu Energy Inc. | **www.candu.ca** |
| CANDU Owners Group | **www.candu.org** |
| DOE – Energy Information Administration | **www.eia.gov** |
| General Fusion | **www.generalfusion.com** |
| Hydro-Québec | **www.hydroquebec.com** |
| Independent Electricity Systems Operator | **www.ieso.ca** |
| International Atomic Energy Agency | **www.iaea.org** |
| International Commission on Radiological Protection | **www.icrp.org** |
| International Energy Agency | **www.iea.org** |
| Natural Resources Canada | **www.nuclear.nrcan.gc.ca** |
| New Brunswick Power | **www.nbpower.com** |
| Nordion | **www.nordion.com** |
| North American Young Generation in Nuclear | **www.naygn.org** |
| Nuclear Energy Institute | **www.nei.org** |
| Nuclear Industry Association | **www.niauk.org** |
| Nuclear Waste Management Organization | **www.nwmo.ca** |
| OECD Nuclear Energy Agency | **www.oecd-nea.org** |
| Ontario Power Generation | **www.opg.com** |
| Organization of Canadian Nuclear Industries | **www.oci-aic.org** |
| Power Workers' Union | **www.pwu.ca** |
| SNC-Lavalin Nuclear | **www.snc-lavalin.com** |
| Statistics Canada | **www.statcan.gc.ca** |
| Terrestrial Energy | **www.terrestrialenergy.com** |
| United Nations Scientific Committee on the Effects of Atomic Radiation | **www.unscear.org** |
| Women in Nuclear | **www.win-canada.org** |
| World Health Organization | **www.who.int/ionizing_radiation/en** |
| World Nuclear Association | **www.world-nuclear.org** |

## ABOUT THE CNA

The Canadian Nuclear Association (CNA) is a non–profit organization established in 1960 to represent the nuclear industry in Canada and promote the development and growth of nuclear technologies for peaceful purposes.

The CNA works to:

- Create and foster a political environment and reasonable regulatory framework for advancing the nuclear industry in Canada.
- Encourage cooperation among various industries, utilities, educational institutions, government departments and agencies, and other authoritative bodies that have a common interest in the development of economic uses for nuclear power and radioisotopes.
- Provide a forum for the discussion and resolution of issues of concern to members, to industry, or to the Canadian public.

## ABOUT THE CANADIAN NUCLEAR FACTBOOK

The Canadian Nuclear Factbook has been published regularly since 2004 by the Canadian Nuclear Association. Every year, 30,000 copies are distributed to schools, universities, information centres at nuclear facilities, industry associations, parliamentarians, and many others. Thousands of copies are distributed free of charge nationally and internationally to individuals and organizations on request. If you wish to order one or more copies of the Canadian Nuclear Factbook free of charge for yourself or an organization, or to access an electronic version, send us an email at **info@cna.ca**.

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