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NUCLEAR ENERGY AND RADIOACTIVE WASTE MANAGEMENT IN CANADA

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Nuclear Energy and Radioactive Waste Management in Canada
(Background Paper)

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EXECUTIVE SUMMARY

Nuclear energy is used by about 30 countries around the world, including Canada, and provides just over 10% of the world's electricity. However, producing this energy generates radioactive waste with no foreseeable use and with a radioactive lifespan that can be of more than one million years.

There is therefore an international consensus on the need to come up with permanent solutions for the long-term storage (i.e., disposal) of this waste. But how is Canada managing its radioactive waste today and how does it plan to manage it in the long term? How are other nuclear energy producing countries addressing this issue?

This paper examines the governance framework for radioactive waste management in Canada and describes the various disposal projects proposed to date and the decision-making process that supports them.

Disposal projects vary according to the different categories of radioactive waste, which require a type of containment and isolation specific to their level of risk in order to protect human health and the environment. For example, low-level radioactive waste, such as contaminated soil and equipment used in nuclear power plants, can be stored long term in near-surface facilities. In comparison, high-level waste, such as spent nuclear fuel, and some intermediate-level waste, such as former nuclear reactor parts, may have to be contained and isolated in deep geological repositories for hundreds of thousands, if not millions, of years.

In Canada, four long-term, low- and intermediate-level waste management projects are expected to be completed in the coming years. Three of these projects involve the disposal of low-level waste owned by Canadian Nuclear Laboratories in near-surface facilities. Two of these projects are already under construction (Port Hope and Port Granby) and the other is in the approval phase (Chalk River). A proposed deep geological repository for the disposal of low- and intermediate-level waste owned by Ontario Power Generation that was in the process of being approved was rejected in its current form following a ratification vote by the Saugeen Ojibway Nation. An alternative solution will have to be considered.

With respect to high-level waste, the Nuclear Waste Management Organization was established in 2002 as a not-for-profit organization to develop and implement a national long-term management plan for all of Canada's spent nuclear fuel. This plan, known as Adaptive Phased Management, is expected to lead to the selection of a suitable site for a deep geological repository.

In addition, technological advances may offer the possibility of reducing waste production or using it more efficiently. Nevertheless, countries that use nuclear energy should consider establishing a long-term management system to safely isolate radioactive waste.

NUCLEAR ENERGY AND RADIOACTIVE WASTE MANAGEMENT IN CANADA

1 INTRODUCTION

Nuclear energy is a source of electricity for some 30 countries around the world, including Canada.[1] As with other types of energy, there are several economic, environmental, social and political factors supporting or discouraging its development and use. For example, in their clean-energy transition, some countries are choosing nuclear energy as a stable, low-carbon source of electricity.[2] Others have raised concerns about the safety, social acceptability and cost effectiveness of this energy source compared to others.[3]

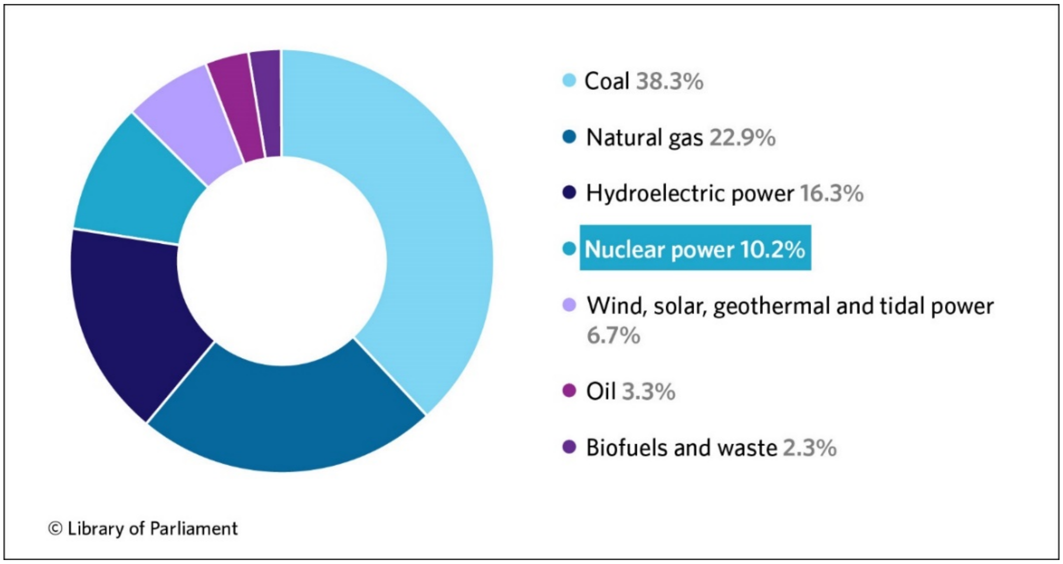
Every country that uses nuclear energy inevitably faces the challenge of managing the resulting waste. What makes nuclear waste different from waste generated by other sources of electricity is that it is radioactive[4] and poses risks to human health and the environment if it is not managed safely. Its lifespan is also an important factor to consider, as some of it can remain radioactive for over a million years.

Currently, most radioactive waste in Canada is stored in interim facilities. However, there is an international consensus on the need to find permanent solutions for the long-term storage (i.e., disposal) of this waste, particularly in deep geological formations for the most highly radioactive waste, such as spent nuclear fuel.[5] Some of these projects are in the planning stage, as in Canada, while others are already in the implementation stage, as in Finland.

2 NUCLEAR ENERGY WORLDWIDE AND IN CANADA

Nuclear energy is the world's fourth-largest source of electricity after coal, natural gas and hydroelectric power. It provides just over 10% of the world's electricity (see Figure 1).

Figure 1 – Global Power Generation, by Energy Source, 2017



Source: Figure prepared by the authors using data obtained from International Energy Agency, "Energy supply," *Data and statistics*.

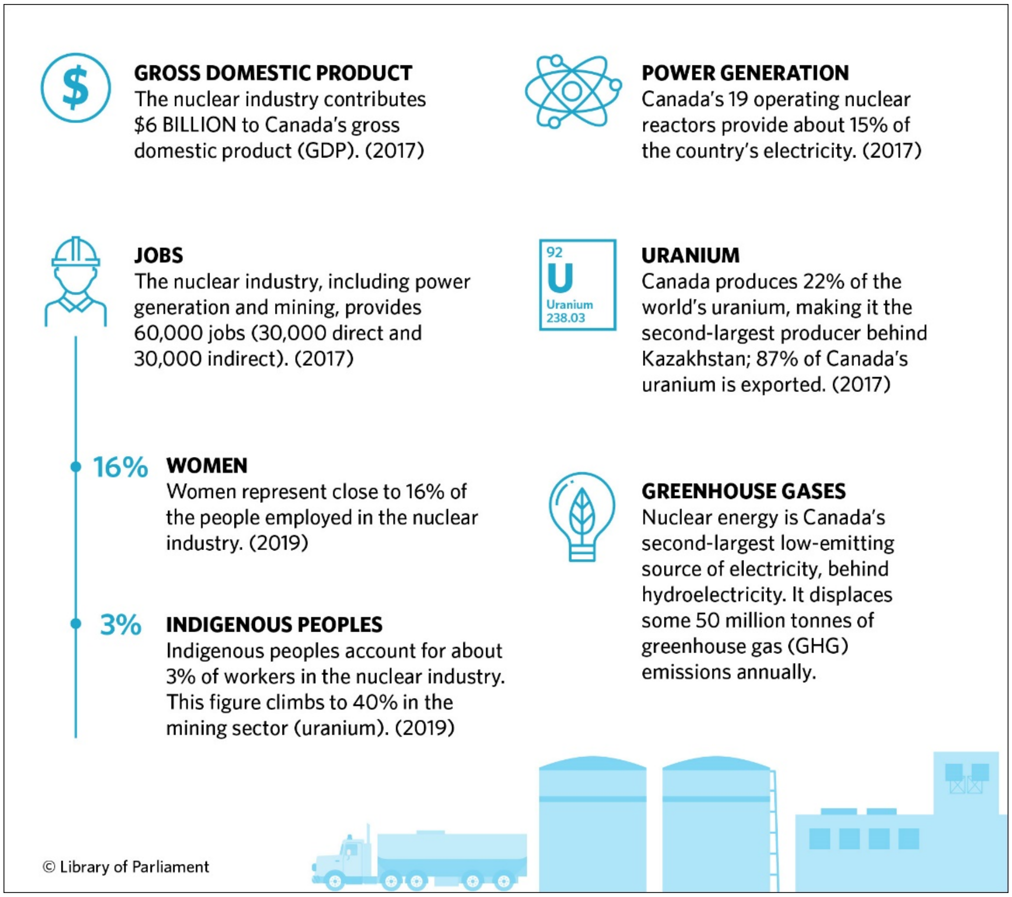
Nuclear energy's place in the world's energy mix has been in gradual decline since the late 1990s, when it accounted for just over 17% of global supply.[6] A temporary decline in global nuclear power generation was also observed following the 2011 accident at Japan's Fukushima nuclear power plant and the subsequent shutdown of the country's nuclear reactors.[7] Some countries are looking at phasing out nuclear energy altogether, such as Germany which has adopted a policy of "Energiewende" ("energy shift") toward renewables.[8]

However, nuclear power generation is growing in some parts of Asia, particularly in China and India, two countries seeking to reduce their reliance on fossil fuels and meet the growing domestic demand for electricity.[9] As well, nearly a dozen countries are considering developing new nuclear programs over the next 20 years, or are already in the process of developing plans to do so.[10]

In 2019, approximately 450 nuclear reactors were online for commercial power generation, and more than 50 new reactors were under construction worldwide.[11] The United States is the main nuclear energy producer (with 32% of world production), followed by France (15%) and China (9%). Canada ranks sixth (with 4% of world production).[12]

Canada's nuclear industry comprises a mix of private-sector companies and public-sector organizations, and encompasses the full nuclear fuel cycle.[13] These activities have an economic, social and environmental impact (see Figure 2).

Figure 2 – Canada's Nuclear Industry at a Glance



Sources: Figure prepared by the authors using data obtained from Natural Resources Canada [NRCan], *Nuclear in Canada*, 2017; NRCan, *Energy Fact Book 2019–2020*, 2019; and MZ Consulting Inc., *Benefits of Nuclear Energy for Canadians*, October 2019.

In Canada, nuclear power is generated by CANDU (CANada Deuterium Uranium) pressurized heavy water reactors using natural (unenriched) uranium. This Canadian technology is also used in six other countries around the world.[14] Other types of nuclear facilities in Canada include uranium mines and mills, fuel processing and fabrication facilities, and nuclear research centres.[15]

In addition to electricity generation, nuclear technology is also used for medical purposes (e.g., cancer treatment), in food and agriculture (e.g., food irradiation) and in many industrial processes.[16]

Whatever the application of nuclear power, each generates different types of radioactive waste.

3 RADIOACTIVE WASTE

Radioactive waste (or nuclear waste) is defined as "any liquid, gas or solid that contains a radioactive nuclear substance and for which there is no foreseeable use."[17] There are four classes of radioactive waste in Canada: (1) uranium mine and mill waste; (2) low-level radioactive waste; (3) intermediate-level radioactive waste; and (4) high-level radioactive waste.[18] Radioactive waste is classified "according to the degree of containment and isolation required" and the "hazard potential of the various types of radioactive waste."[19]

Furthermore, it is not the volume of the waste, but its radioactivity, that determines the level of risk. Table 1 presents an inventory of radioactive waste in Canada.

Table 1 – Inventory of Radioactive Waste in Canada

Type of Waste	Waste Inventory at the End of 2016	Waste Inventory Projected to 2050	Waste Inventory Projected to 2100
Waste from uranium mines and mills	387 million tonnes	n/a[a]	n/a[a]
Low-level radioactive waste	2,395,385 m^3 (944 Olympic-sized pools[b])	2,768,635 m^3	3,095,035 m^3
Intermediate-level radioactive waste	33,155 m^3 (14 Olympic-sized pools)	58,430 m^3	82,824 m^3
High-level radioactive waste	11,089 m^3 (5 Olympic-sized pools)	20,262 m^3	21,835 m^3

Notes: a. No projection is available for uranium mine and mill waste as the inventory depends on production levels.

b. An Olympic-sized swimming pool is the equivalent of 2,500 m^3.

Source: Table prepared by the authors using data obtained from Natural Resources Canada, *Inventory of Radioactive Waste in Canada 2016*, 2018, p. 10.

Uranium mine and mill waste has low levels of radioactivity and, as a result, its processing conditions are different from those for other types of radioactive waste. Waste from uranium mining and processing is managed on site and long-term containment is provided by flooding or covering, two techniques that "reduce acid generation and the release of gamma radiation and radon gas."[20]

3.1 LOW-LEVEL RADIOACTIVE WASTE

In Canada, low-level radioactive waste is mostly historic waste left behind by more than 60 years of government nuclear research (obsolete research facilities, contaminated soils, etc.).[21] The rest is mainly "contaminated equipment from the operation of nuclear power plants," such as cables, protective clothing and tools.[22] Globally, this type of waste accounts for about 95% of the volume but only 2% of the radioactivity of all radioactive waste.[23] Its half-life, the time required for the radioactivity of a substance to decrease to half its value, is generally less than 30 years.[24] In the long term, it can be stored in near-surface facilities, such as artificial containment mounds or engineered trenches with base liners and waterproof covers.

Some countries are also considering storing their low-level waste in deep geological repositories that would also be used for the disposal of intermediate- and high-level waste. This would reduce the number of repositories in a given area and simplify radioactive waste management in the long term.[25] However, according to the International Atomic Energy Agency (IAEA), co-disposal of waste could make designing deep geological repositories more complex.[26]

3.2 INTERMEDIATE-LEVEL RADIOACTIVE WASTE

Intermediate-level radioactive waste consists mainly of old nuclear reactor parts, and some radioactive sources used in radiotherapy. It accounts for 3% to 5% of the radioactivity of all radioactive waste.[27] Some short-lived intermediate-level waste may be stored near the surface. However, most of this waste, which has a long half-life, requires containment in facilities at intermediate depths (in the order of tens of metres to a few hundred metres).[28]

3.3 HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive waste refers to used (or spent) nuclear fuel. This waste accounts for about 95% of the radioactivity of all radioactive waste.[29] A period of about one million years is required for the spent fuel to return to the level of radioactivity of natural uranium.[30] At the end of its useful life, this waste is stored in cooling pools and then isolated in dry storage containers pending final disposal in deep geological repositories, which are "deep, stable geological formations at depths of several hundred metres or more below the surface."[31]

4 GOVERNANCE OF RADIOACTIVE WASTE MANAGEMENT IN CANADA

Canada's nuclear sector falls primarily within the jurisdiction of the federal government, which is responsible for policy, research and development, and the regulation of nuclear energy and materials, including radioactive waste management.[32] However, the decision whether or not to invest in nuclear energy rests with the provinces, which are responsible for determining which approaches and technologies to use to meet their electricity needs.[33]

In 1996, Canada developed a Radioactive Waste Policy Framework that provides a set of policies, legislation, lead organizations and principles governing the institutional and financial arrangements for radioactive waste management in Canada.[34] One key management principle is that of "polluter pays," meaning that the producers and owners of radioactive waste are responsible for its management and the associated funding.[35] This policy also recognizes that the arrangements may be different for various types of waste. Historic low-level radioactive waste falls under federal jurisdiction.

Radioactive waste management in Canada is governed primarily by two federal statutes. First, the *Nuclear Safety and Control Act*[36] and its regulations form the regulatory framework for nuclear energy in Canada. Under the Act, the Canadian Nuclear Safety Commission (CNSC) is the independent federal agency responsible for the regulation, licensing and oversight of nuclear activities and facilities in Canada, including radioactive waste.[37]

Second, the *Nuclear Fuel Waste Act*[38] provides the federal government with a framework for making decisions on the management of nuclear fuel waste in Canada. Under this Act, the Nuclear Waste Management Organization (NWMO) was created in 2002 to develop and implement the long-term management plan for nuclear waste.[39]

As a producer and user of nuclear energy, Canada is bound by the international conventions to which it is a party and that aim to regulate the nuclear sector. For instance, the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* is a legally binding international instrument on radioactive waste.[40] Under this convention, Canada is required to undergo periodic peer review of its national spent fuel and radioactive waste management program.[41] The last evaluation took place in 2018.[42]

This international framework on nuclear safety is administered by the IAEA, which also develops safety standards, including for the disposal of radioactive waste and the safety of nuclear fuel cycle facilities.[43]

5 LONG-TERM MANAGEMENT OF RADIOACTIVE WASTE

There are various long-term radioactive waste disposal solutions around the world. They vary according to several factors, such as the type and quantity of nuclear waste, the national legislative framework in place, and the geological formations present in the country.

5.1 LONG-TERM MANAGEMENT OF LOW- AND INTERMEDIATE-LEVEL RADIOACTIVE WASTE

While a number of long-term low- and intermediate-level radioactive waste management facilities are in operation worldwide, the strategies for managing this waste vary. Some countries, including France and Spain, have so far opted to store low-level radioactive waste and some short-lived intermediate-level waste in near-surface facilities.[44] Others, such as Finland, have chosen to dispose of these types of waste in deep geological repositories.[45]

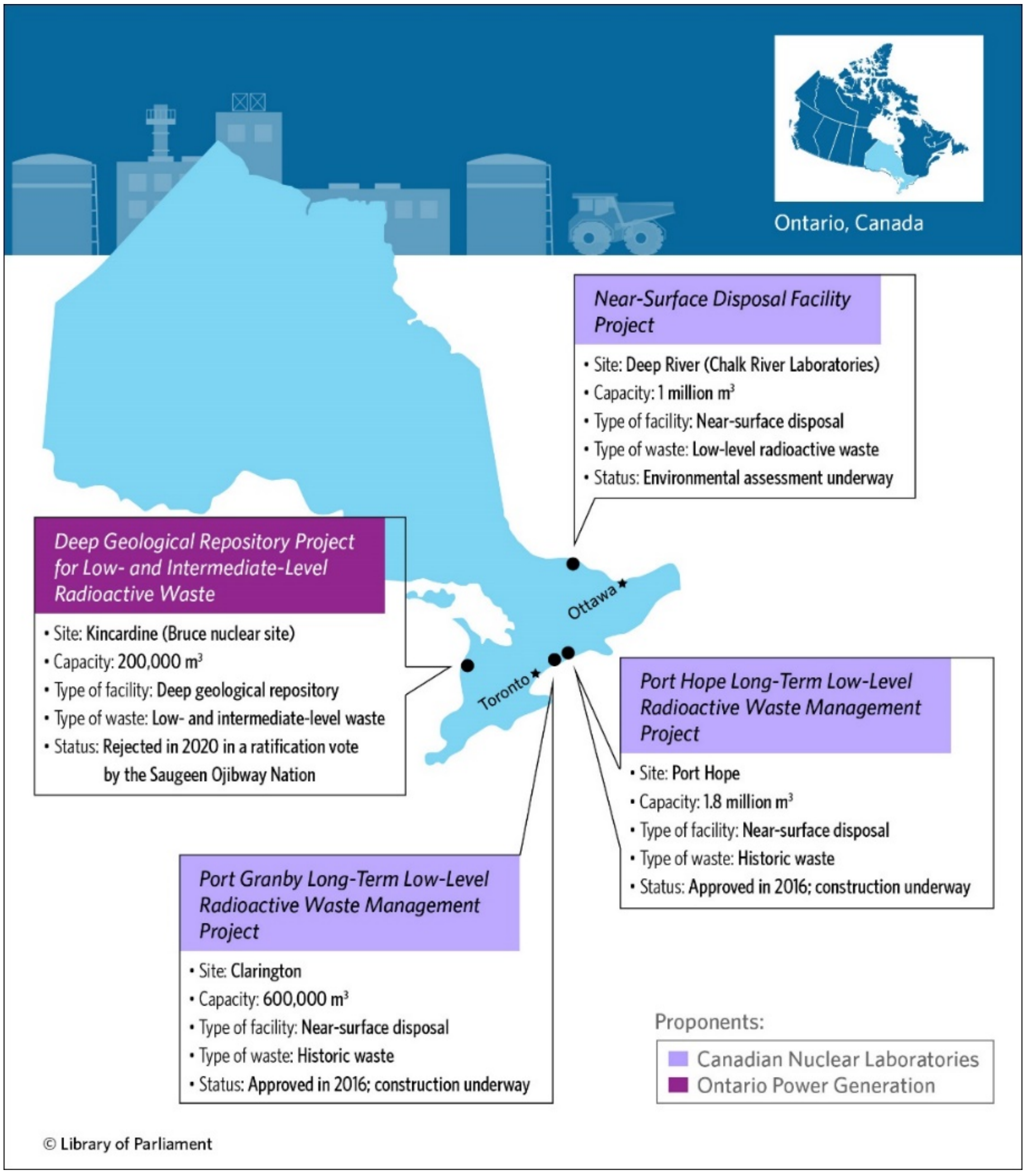
In the United States, low- and intermediate-level radioactive waste is disposed of separately. To date, five near-surface sites are used for the disposal of low-level radioactive waste from civil nuclear energy. The only deep geological repository in operation in the country is reserved for long-lived intermediate-level radioactive waste from military sources.[46]

There is also the possibility that different management strategies may be developed in the same country, particularly if responsibility for radioactive waste management is shared by several organizations. This is the case in Canada, where three projects for the long-term near-surface disposal of low-level radioactive waste and one project for a deep geological repository for low- and intermediate-level radioactive waste are being planned.

5.1.1 Canadian Context

In Canada, four long-term low- and intermediate-level radioactive waste management projects have been proposed in recent years (see Figure 3). These projects would allow Canada's two main radioactive waste managers (Canadian Nuclear Laboratories and Ontario Power Generation) to dispose of 3.6 million m^3 of radioactive waste.

Figure 3 – Long-Term Low- and Intermediate-Level Waste Management Projects in Canada



Sources: Figure prepared by the authors using data obtained from Government of Canada, *Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste*; Government of Canada, *Near Surface Disposal Facility Project*; Canadian Nuclear Safety Commission [CNSC], "NRCan's Port Hope Long-Term Low-Level Radioactive Waste Management Project," *Completed EAs*; and CNSC, "Port Granby Long-Term Low-Level Radioactive Waste Management Project," *Completed EAs*.

5.1.1.1 Canadian Nuclear Laboratories

In Canada, historic waste and waste from nuclear research facilities (including prototype reactors) are the property of the federal government, which has given responsibility for managing it to a Crown corporation, Atomic Energy of Canada Limited (AECL). In 2016, these types of waste accounted for 94% of low-level waste (71% of which is historic waste) and 62% of intermediate-level waste in Canada.[47]

Following the Government of Canada's decision to restructure AECL, Canadian Nuclear Laboratories (CNL) was created in 2014 under the government-owned, contractor-operated model to be responsible for the long-term management of Canada's historic radioactive waste.[48] Between 2009 and 2015, AECL underwent a reorganization through which virtually all of the Crown corporation's employees and operating licences were transferred to CNL.[49] AECL is now responsible, among other things, for overseeing the decommissioning and waste management activities assigned to CNL.[50] CNL inherited the Port Hope Area Initiative,[51] initially managed by Natural Resources Canada, which comprises two projects (Port Granby and Port Hope) and aims to manage historic low-level waste and remediate contaminated sites in the area.[52] The Port Granby and Port Hope projects each underwent an environmental assessment process initiated in 2001.[53] The CNSC granted regulatory approval in both cases.[54]

In 2012, the Government of Canada announced that it would invest $1.28 billion over 10 years for the implementation phase of both projects.[55] Construction of the containment mounds began in 2016, and the covering and closure of the mound at each of the two sites are expected to be completed by 2023–2024. Once the sites are closed, CNL has planned a monitoring and maintenance phase that is expected to last "hundreds of years."[56]

CNL is also proposing to construct a near-surface containment mound at Chalk River, northwest of Ottawa, to manage 1 million cubic metres of low-level radioactive waste for a minimum period of 50 years.[57] Nearly 90% of the waste would come from the research laboratories and nuclear facilities in Chalk River, home to Canada's largest nuclear laboratories. The remaining waste would come from laboratories in Whiteshell, Manitoba, and from Canadian universities and hospitals. Due to a modification to the project, the environmental assessment initiated in 2016 is still ongoing.[58]

5.1.1.2 Ontario Power Generation

Ontario Power Generation (OPG) is Ontario's largest electricity corporation and owns 19 of Canada's 22 CANDU reactors. In 2016, OPG was responsible for 4% of the country's low-level radioactive waste and 36% of its intermediate-level radioactive waste.[59] Natural Resources Canada expects that the amount of radioactive waste managed by OPG will increase in the coming years as the Bruce, Darlington and Pickering nuclear reactors are decommissioned.[60]

In order to permanently dispose of its low- and intermediate-level waste, OPG proposed building a 680-metre-deep geological repository at the Bruce Nuclear Generating Station site in Kincardine, which is located within the traditional territory of the Chippewas of Saugeen First Nation and the Chippewas of Nawash Unceded First Nation (collectively referred to as the Saugeen Ojibway Nation).[61] OPG's project was first submitted in 2006 to the Canadian Environmental Assessment Agency (now the Impact Assessment Agency of Canada). In 2012 the Agency and the CNSC established a Joint Review Panel (JRP) to assess the project's potential environmental impacts.[62]

In May 2015, after two years of public hearings, the JRP issued a favourable decision with 97 recommendations, presented in a report. The JRP concluded that OPG's project "is not likely to cause significant adverse environmental effects" if the recommended mitigation measures are properly implemented.[63] The then-federal environment minister did not make a decision on the project prior to the federal election in the fall of 2015.

In 2016, the newly elected federal government decided to extend the time limit for issuing a decision statement by 243 days to allow it time to assess the JRP's findings.[64] In 2017, the then-environment and climate change minister sent OPG a letter asking them to conduct further consultations with the Saugeen Ojibway Nation and to assess the potential cumulative effects of the project on this community. In particular, the minister stressed the importance of obtaining the support of this Indigenous community for the continuation of the project. She also mentioned that her final decision would be based not only on science, but also on Indigenous traditional knowledge.[65]

In this regard, OPG has committed not to proceed with its project without the consent of the Saugeen Ojibway Nation.[66] The corporation organized 22 public meetings with members of this community between February and November 2019 to discuss the proposed project.[67] On 31 January 2020, a ratification vote was held by the Saugeen Ojibway Nation to allow all community members aged 16 and older to have their say on OPG's proposed Deep Geological Repository. Of the 1,232 community members who voted, 1,058 rejected the project.[68] In light of this result, OPG announced that it will terminate the project in its current form and will seek an alternative solution.[69]

5.1.1.3 NB Power and Hydro-Québec

NB Power and Hydro-Québec, each of which owns a CANDU reactor, do not have a final plan for the long-term management of their radioactive waste. However, they are continuing discussions with industry partners on a possible final disposal site at a location yet to be determined.[70] Both public utilities participate in decommissioning and waste management peer and working groups as members of the CANDU Owners Group.[71] In 2016, these two companies together were responsible for managing roughly 2% of intermediate-level and less than 1% of low-level radioactive waste in Canada.[72]

5.2 LONG-TERM MANAGEMENT OF HIGH-LEVEL RADIOACTIVE WASTE

Unlike for low- and intermediate-level waste, there are no operational long-term disposal projects for high-level radioactive waste (spent fuel) anywhere in the world. Over the past few decades, several organizations and countries, including Canada, have been involved in research to identify solutions for the long-term disposal of spent fuel.[73]

Final disposal in deep geological repositories is widely recognized by the international scientific community and nuclear energy-producing countries as the preferred option for containing spent fuel.[74] Such repositories would be built in stable geological formations where protection is provided by a "multi-barrier system" – where the barriers are natural (such as rock, salt and clay) and engineered (such as fuel pellets, elements and containers).[75]

To date, only a few countries are at an advanced stage of development of this type of project – such as Finland, France and Sweden, where sites have already been identified.

Finland is the only country to have started construction of a deep geological repository.[76] Posiva, an expert organization responsible for the final disposal of spent fuel from Finland's two nuclear power plants, obtained its construction permit for the ONKALO project in 2015.[77] Located in the rock formations of Olkiluoto Island (where there is also a nuclear power plant), the repository is built at a depth of about 450 m and is expected to be operational in 2020 for up to a century.[78] The spent fuel will be encapsulated in corrosion-resistant copper canisters, which will be embedded in swelling clay.[79]

Prior to government approval of the project, it was first approved by the host municipality (Eurajoki) and the Finnish Radiation and Nuclear Safety Authority. Eurajoki also had a right of veto on the matter. The Finnish Parliament then ratified the government's decision by a large majority.[80]

Most other countries that are considering building a deep geological repository for spent fuel are at the project development stage or are identifying a potential site, as is the case for Canada.

5.2.1 Canadian Context

In Canada, spent nuclear fuel (or high-level radioactive waste) is currently stored in various interim facilities designed for this purpose and is managed by the nuclear power plant operator. When spent fuel is removed from a reactor, it is placed in a cooling pool for seven to 10 years to decrease their heat and radioactivity. It is then transferred to a concrete dry storage container or silo that is placed in above-ground facilities at the reactor site.[81]

In the 1970s, the federal and Ontario governments directed AECL to develop the concept of deep geological disposal of spent fuel.[82]

In the late 1980s, two House of Commons standing committees studied the issue and made several recommendations regarding the funding and governance of Canada's nuclear fuel waste management program.[83]

During the same period, an independent environmental assessment panel was created to review the concept of a deep geological repository and make recommendations for the management of spent fuel in Canada.[84] At the end of its decade-long study, the panel concluded that the success of long-term spent fuel management depends not only on project safety, but also on its social acceptability.[85] As the panel's work wrapped up, "it became clear that the Government of Canada needed to put in place a process to ensure a long-term management approach for Canada's spent fuel would be developed and implemented."[86] Given the small volume of this fuel in Canada, "it was determined that a national solution would be in the best interest of Canadians."[87]

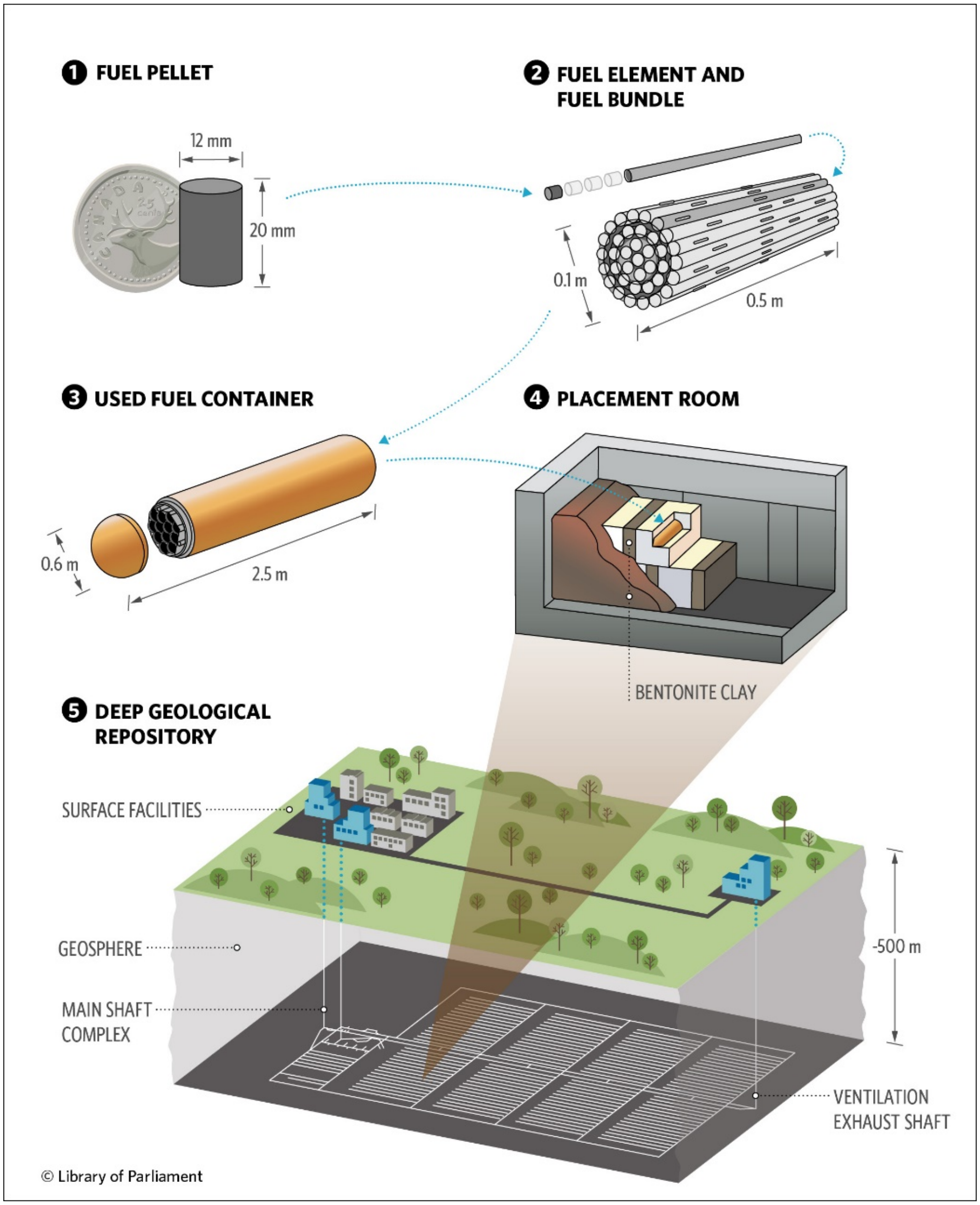
5.2.1.1 Adaptive Phased Management

Under the *Nuclear Fuel Waste Act*, the owners of nuclear fuel waste (NB Power, Hydro-Québec, OPG and AECL) created the NWMO. Governance of the NWMO is provided by the member corporation (NB Power, Hydro-Québec and OPG), a Board of Directors that oversees the NWMO and takes the lead in the development of its strategic priorities, and an Advisory Council that reviews its work and provides advice.[88]

The NWMO was directed to develop and implement a plan for the long-term management of all spent fuel in Canada. It studied three methods and chose the one known as Adaptive Phased Management (APM).[89] The federal government gave its approval for APM in 2007 following a three-year public consultation (2002 to 2005).[90] This management system is based on "phased and adaptive decision-making" that is "responsive to advances in technology, research, Indigenous Knowledge, and societal values," supported by public engagement and continuous learning.[91]

APM requires that spent fuel be contained and isolated in a deep geological repository. This involves a system of underground tunnels and rooms for storing spent fuel, as well as space for maintenance and monitoring facilities. The repository will be constructed in a stable formation of sedimentary or crystalline rock at a depth of approximately 500 m below ground and covering an area of approximately 2 km by 3 km.[92] The multi-barrier system includes the fuel pellet, the fuel element and fuel bundle, the used (spent) nuclear fuel container, the bentonite clay and the geosphere[93] (see Figure 4).

Figure 4 – Stages in the Multiple-Barrier System for the Disposal of Used Nuclear Fuel



Sources: Figure prepared by the authors using data obtained from Canadian Nuclear Association, *The Canadian Nuclear Factbook 2019*, p. 50; and Nuclear Waste Management Organization, *Ensuring Safety: Multiple-Barrier System*, Backgrounder, 2015.

APM will be implemented over several decades through a six-phase process:

1. site selection and regulatory approval;
2. site preparation and construction;
3. operations;
4. extended monitoring;
5. decommissioning and closure; and
6. post-closure monitoring.[94]

Although the primary intent of disposal in a deep geological repository is not to remove spent fuel, one of the characteristics of APM is the concept of "retrievability." This is to allow the removal of spent fuel during all phases of the project, including for safety reasons.[95] According to the planning timelines, operations could begin by 2040.[96] According to the NWMO,

> the total lifecycle cost of Adaptive Phased Management (APM) – from the beginning of site selection in 2010 to the completion of the project – is approximately $23 billion (in 2015 dollars). This includes costs already paid for and also accounts for more than 160 years of lifecycle activity at the facility.[97]

The NWMO has identified several guiding principles for selecting a deep geological repository site. These principles include safety; the importance of meeting or exceeding regulatory requirements; participation in the decision-making process; respect for Indigenous rights, treaties and land claims; and acceptance by an informed and willing host community.[98]

The site selection process comprises nine stages, including initiation of the process, initial screening of communities, preliminary assessment of communities, site confirmation from the host community, regulatory approval, construction and operation.[99] Initially, 22 communities expressed interest in the project – some have now withdrawn and others were ruled out as a result of the studies conducted.[100] As of 4 February 2020, two potential host regions in Ontario were still in the running: the Township of Ignace and the Municipality of South Bruce.

Before proceeding with the final site selection (planned for 2023), the NWMO will need to obtain confirmation of acceptance from the host community concerned. In addition, "the project will only proceed with the involvement of the community, First Nation and Métis communities in the area, and surrounding communities working together to implement it."[101] The NWMO will also be required to demonstrate that the project meets the regulatory safety requirements established by the CNSC, which include the "criteria used to assess the suitability of potential sites from the inception of the siting process."[102]

Once these requirements are met, the regulatory review process will continue and include the application of a comprehensive licensing system at each stage of the repository life cycle.[103] The CNSC will be responsible for determining whether all regulatory requirements have been satisfied, but "a licensing decision by the CNSC can only be taken after the successful completion of the environmental assessment."[104]

6 TECHNOLOGICAL INNOVATIONS TO REDUCE WASTE

In Canada and internationally, one of the guiding principles of radioactive waste management is to reduce its production. That is why the nuclear industry has developed techniques for reprocessing (or recycling) spent fuel and is continuing its research with the aim of developing two processes: partitioning and transmutation.[105] These processes would respectively separate certain radioactive materials from the spent fuel and reduce the half-life of high-level waste.[106]

Reprocessing technologies are being used or planned in some countries to reuse spent nuclear fuel from light water reactors (which run on enriched uranium).[107]

Research is underway in China to demonstrate that CANDU reactors (which run on natural uranium) "can recycle used fuel from other nuclear power plants, reducing the volume of nuclear waste."[108] However, such an operation would be complex in Canada in the current context as it would require building new light water reactors or importing spent fuel from enriched uranium.

Partitioning and transmutation technologies, while reducing the amount of high-level radioactive waste, would not completely eliminate it.

These three processes present significant technical and financial challenges.[109] Some countries, such as Sweden, have stopped reprocessing spent fuel, while others, such as the United Kingdom, are considering discontinuing the practice "due to the lower cost option of direct placement of used fuel in a deep geological repository."[110]

Aware of the challenges associated with the long-term management of radioactive waste, the nuclear industry is seeking to reduce waste generation at source and reduce the level of radioactivity. Research is underway to develop a new generation of nuclear fission reactors (Generation IV) in order to improve "the efficiency of energy production from nuclear fuel and significantly reduce nuclear waste in spent fuel."[111] As well, research is ongoing to develop nuclear fusion reactors so as to avoid the production of long-lived radioactive nuclear waste.[112]

Some models of small modular reactors under development could also "reduce the amounts of radioactive waste from existing reactors by closing the fuel cycle, where spent fuel is processed and partly reused."[113] Canada has developed a small modular reactor roadmap and has pledged to the Generation IV International Forum to collaborate on research and development into the next generation of nuclear reactors.

7 CONCLUSION

A significant proportion of the world's radioactive waste is currently stored in interim facilities, and the long-term management of this waste is an important issue for the nuclear industry. Although technological advances may offer the possibility of producing less waste or using it more efficiently, countries that use nuclear energy should consider setting up a long-term management system to safely isolate radioactive waste. Many years of research have identified different solutions depending on the type of waste and the situation of each country.

With respect to the long-term management of spent fuel, several countries, including Canada, have opted for deep geological repositories and are at different stages of the process, from conceptualization to project construction. For the most part, the final form of the project (including the management system and site selection) has yet to be determined.

In Canada, as in many countries seeking a suitable site for a deep geological repository, the participation and acceptance of the surrounding communities will be essential to the implementation of such a project.

NOTES

1. World Nuclear Association [WNA], *Nuclear Power in the World Today*.
2. Nuclear energy is considered a low-carbon energy source when taking into account emissions over the entire life cycle, from uranium mining to decommissioning of nuclear power plants. Nuclear power generation is emission-free. See Canadian Nuclear Association [CNA], *Why nuclear energy?*; and Natural Resources Canada [NRCan], *The Canadian Nuclear Industry and its Economic Contributions*.
3. International Energy Agency [IEA], *Nuclear*.
4. CNA defines radioactivity as the

   > characteristic of some *isotopes* to undergo spontaneous *decay* of their *nuclei*, which causes the emission of electromagnetic waves (such as *gamma rays*) or particles (such as *alpha particles* and *beta particles*). Radioactivity is measured in *curies* (Ci) or *becquerels* (Bq).

   See CNA, "Glossary: Radioactivity," *Resources*.
5. WNA, *Storage and Disposal of Radioactive Waste*; and Nuclear Waste Management Organization [NWMO], *What Other Countries Are Doing*.
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