The Nuclear Option in Canada

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Canada has a long history of nuclear power development. Under the constitution, nuclear energy is a federal responsibility. In 1946 the government passed the Atomic Energy Control Act and established the Atomic Energy Control Board (AECB) as the regulatory and administrative authority over nuclear projects in Canada. Today, nuclear projects are administered under the Nuclear Safety and Control Act (NSCA, 1997), which replaced the Atomic Energy Control Act, and replaced the AECB with the Canadian Nuclear Safety Commission (CNSC). Canada developed the CANDU (CANada Deuterium Uranium) reactor in the 1960s and there are now 19 CANDU reactors operating in Canada (18 in Ontario and 1 in New Brunswick) providing about 16% of Canada's electricity. Another dozen CANDU reactors operate outside Canada. Canada continues to market CANDU technology worldwide (the commercial reactor business is now owned by SNC Lavalin) although no new reactors have been built in recent decades. Canada is deeply invested in the current push to develop Small Modular Reactors (SMRs that use generation IV nuclear technology), touted as the future of nuclear energy. In this essay I summarize information from published reports to explore six issues that will influence whether SMR technology will be successful in Canada.

1. History of nuclear power in Canada

Canada's long history of research and development of nuclear energy began in 1942 when a joint British-Canadian laboratory, the Montreal Laboratory, was set up in Montreal under the administration of the National Research Council of Canada (NRCC) to develop a design for a heavy water nuclear reactor (the precursor to the CANDU). Canada also established the Chalk River Nuclear Laboratory NW of Ottawa in 1944 and in 1945 this laboratory activated the first successful nuclear reactor outside the United States. In 1952 the government created Atomic Energy of Canada Ltd (AECL) to promote peaceful use of nuclear technology and AECL took over operation of the Chalk River laboratory from NRCC. In 1962, Canada's first nuclear power plant (a collaboration with the Ontario Hydroelectric Power Commission) went online near Chalk River. This power plant was a demonstration of the CANDU reactor design. Starting in 1961, AECL led the construction of 24 commercial CANDU reactors in Ontario, Quebec, and New Brunswick. Not all of these projects were commercially successful, and Quebec eventually abandoned nuclear in favour of hydroelectricity development in James Bay. In 2014, AECL created a wholly owned subsidiary to look after its nuclear operations, the Canadian Nuclear Laboratories (CNL). CNL is responsible for managing Canada's radioactive waste, decommissioning now defunct nuclear facilities located at the Chalk River (ON) and Whiteshell (MB) Laboratories, ensuring that Canada's nuclear science and technology capabilities support federal nuclear responsibilities, and providing industry, on a commercial basis, with in-depth nuclear science and technology expertise. In 2015, all the responsibilities of CNL were transferred, under contract, to a private consortium consisting of SNC-Lavalin, Fluor, Jacobs Engineering, and Energy Solutions. AECL now exists only to administer this contract.

The CNSC has total regulatory authority over the licensing, operation and safety of nuclear reactors in Canada. The CNSC also has regulatory authority over mining, processing and transportation of nuclear materials in Canada, the use of nuclear materials in medicine and industry, and the management and disposal of nuclear waste. The CNSC is responsible for keeping Canadians informed of any effects of nuclear activity on human health or the health of the environment. Under the 2012 revisions to the Canadian Environmental Assessment Act, the CNSC administers environmental assessments of all proposed nuclear projects in Canada, including deciding what level of review a proposal will receive. The CNSC is, thus, a very critical and powerful agency in Canada controlling virtually everything having to do with the use of nuclear materials. It reports to the Minister of Natural Resources but is independent of government. Anti nuclear groups believe that CNSC is a "captured regulator", overly influenced by the industry.

Particularly relevant to the current emphasis on small modular reactor technology is the fact that from 1967 to 1970, Canada developed an experimental miniature nuclear reactor named SLOWPOKE (acronym for Safe LOW-POwer Kritical Experiment). The first prototype was assembled at Chalk River and many SLOWPOKEs were built, mainly for research. These were low power reactors capable of generating around 20 kW. Two SLOWPOKEs are still in use in Canada and one in Kingston, Jamaica.

Canada is a charter member of the Generation IV International Forum (GIF) initiated by the US Department of Energy and chartered in 2001. GIF has identified 6 SMR reactor concepts on which to focus research and development, and the members are committed to work on one or more of those concepts. Chalk River is currently partnering with Global First Power to construct one design, a Micro Modular Reactor designed by Ultra Safe Nuclear (a new company based in Seattle dedicated to small modular nuclear technology). The project is going through the review process in Canada with a timeline to be operational by late 2025. This is one of ten SMR projects at the review stage in Canada. Another is the Terrestrial Energy molten salt SMR mentioned in Henry Sielmann's essay published on the website. No commercial SMR is as yet operational in Canada or anywhere else in the world.

Pros: Canada has a long history with nuclear power and only one serious accident (in 1952) at the Chalk River facility. 16% of Canada's electric power comes from nuclear. Even as construction of new nuclear plants waned in the 1980s Canada has continued near the forefront of research on nuclear power. Canada has the experience and the expertise to build and operate new nuclear facilities if the decision is to go ahead with more nuclear.

Cons: It has been many decades since Canada has actually constructed a commercial nuclear facility. Few new plants have been constructed anywhere in the world since 1990 although there has been a recent uptick in capacity increase. That means global experience with modern nuclear design is somewhat limited.

2. Small Modular Reactors – the new technology:

Almost all existing commercial nuclear power stations are large installations capable of generating 1000 MW or more (such power stations may include more than one reactor). For example, the Bruce power plant in Ontario was for many years the largest nuclear installation in the world, generating 6430 MW from 8 CANDU reactor units. By comparison, the Pt. Lepreau plant in New Brunswick has a rated capacity of 630 MW from one CANDU reactor.

SMRs are much smaller, <300 MW by definition, and are designed to have many advantages over traditional large reactors. For example, rather than simply producing electricity, SMRs could also be used as a source of heat for district heating, heat for industrial processes, and energy to produce carbon free fuels like hydrogen. Because these reactors are small, they could be built to a standard design so that the necessary parts could be fabricated in a centralized factory and transported to the site where the reactor would be assembled. They could also be repaired and refueled in the same way, at a centralized facility. The cost of each reactor would be much smaller than that of a large reactor so that financing would be easier. Small reactors can be coupled, as the CANDUs are at the Bruce facility, to generate any required amount of power but with buildout phased over time. Finally, these small reactors could be integrated with other small scale energy sources like wind and solar. The nuclear reactor would provide base load to fill in the times when wind and solar were not generating, providing a stable source of electric power.

Most large commercial reactors currently in operation are Generation II technology. A few reactors designated Generation III are in operation in Japan. SMRs, which are all still in the design stage, are Generation IV reactors. Each movement up the scale from Generation I to Generation IV has involved increased safety, increased standardization of design (easier to maintain and repair) and increased fuel efficiency (producing less radioactive waste). Some SMRs can also burn spent fuel from large nuclear plants, in the process rendering it less radioactive and safer to store.

About 50 SMRs are in the design and testing phase around the world. Six designs are being developed by the GIF, of which Canada is a member. At least four of the designs incorporate features from existing reactors, which provides a good basis for further R&D and is likely to mean that they can be in commercial operation before 2030. GIF members are committed to sharing research and development information on the six reactor technologies. The objective is to have these technologies (or a successful subset) ready for deployment between 2020 and 2030. All six technologies represent advances in sustainability (operating life), cost savings, safety, and reliability. All are considered resistant to or unsuitable for nuclear proliferation (i.e. they don't generate nuclear material suitable for bombs). Four are designed for hydrogen production as well as electricity generation.

Two of the ten designs being reviewed by CNSC have reached the point that project start could begin. One of those is the Ultra Safe Nuclear project at Chalk River, the other is a small (4MW) high temperature reactor for U.-Battery Canada. The Terrestrial Energy integrated molten salt reactor is one of the designs being reviewed by CNSC and has completed the first phase of review. Terrestrial Energy was also the first private sector nuclear company to join GIF. Other information relevant to the review and licensing of these project proposals is available at: https://nuclearsafety.gc.ca/eng/reactors/power-plants/pre-licensing-vendor-design-review/index.cfm#R2. Some of the design proposals being reviewed by CNSC appear not to be from the list of 6 designs designated for research and development by the GIF. If too many designs are ultimately approved for commercial use in Canada it will make it difficult to realize the projected cost savings resulting from building to a standard design.

Pros: SMR incorporate the latest (Generation IV) technological innovations intended to dramatically improve safety, reliability, flexibility, and utility of the reactor. Their relatively small size and energy output means the reactors can be designed for targeted purposes. Because they are modular the necessary parts can be fabricated in a central facility and shipped to the reactor site. They can also be maintained and refueled at a central facility. Small reactors can be constructed at lower cost, allowing greater ease of financing. Some SMRs are designed to run on spent fuel from large reactors and so could help with the problem of nuclear waste. SMRs will run on a very small amount of fuel, so that their generation of waste will be relatively small.

Cons: Since SMRs are still only in design stage any perceived benefits remain theoretical. However, several models are entering the prototype construction phase so it will be apparent in a few years whether the theoretical expectations can be realized. The prototypes under construction in Russia, China, and Argentina are all dramatically over budget, which means it is much too early to draw conclusions about SMR cost. Although the cost of individual SMRs should be considerably less than that of a large reactor on a per unit energy basis they will still be more costly than wind or solar and, until efficient designs are realized, more costly per unit of energy than gas or coal. Some of the cost benefits of modular design will also only be realized if the country settles on a single design.

3. Public attitude to Nuclear Power.

Public opposition to nuclear power emerged in the US in the early 1960s, spearheaded by citizens opposed to having a nuclear power station constructed near where they lived. By the late 1960s members of the scientific community were also voicing concern about the potential for nuclear accidents, nuclear proliferation, nuclear terrorism, and radioactive waste disposal. By the mid 1970s, nuclear power was becoming an issue of major public concern in all countries with nuclear programs and there were large public protests in some countries. The Three Mile Island nuclear accident in 1979 served to harden public attitudes. Public and scientific concern led to an increasingly stringent regulatory framework that greatly increased the cost of new reactor construction. Public antipathy also narrowed the options for successful project siting. The extended requirements for licensing, safety measures, and public consultation resulted in project costs quadrupling by 1980. Construction of new nuclear plants declined dramatically in the 1980s and, although overall nuclear safety was good, high profile events like Chernobyl (1986) and Fukushima (2011) have kept public concern alive. Total generating capacity has stayed about the same, 350 gigawatts, since the end of the 1980s.

Attitudes toward nuclear energy appear strongly polarized in Canada. Most environmental groups and many citizens groups are strongly opposed to any further development of nuclear energy in Canada and many would like to see existing nuclear plants phased out. Some also argue that, because the new generation of nuclear plants is still in development, any allocation of resources to nuclear distracts from the urgent need to transform the energy economy within a few decades. By contrast, the nuclear industry and nuclear professionals feel that most of the concerns are ill informed and misguided. These groups see a strong future for nuclear energy in Canada and believe it has an important role to play in developing the zero carbon economy. This polarization makes it difficult for the average person to make an informed judgment.

A survey of public attitudes to nuclear in Canada was performed by the firm Innovative Research Group on behalf of the Canadian Nuclear Association (CNA is the trade association for the Canadian Nuclear Industry) in 2011 and 2012. Its purpose was to assess the impact of a major year long publicity program to raise awareness of the benefits of the nuclear industry. However, public attitudes toward nuclear hardly changed between the two surveys. The major findings of the survey were:

1. Nuclear was the second least supported form of electricity generation (after coal) with 37% support. BC had the second lowest level of support at 33% (Quebec was lowest). Only Ontario reported more than 50% support (54%).
2. A majority of Canadians (63%) see nuclear power generation as "expensive". A majority also believe the word "dangerous" describes nuclear energy either extremely or very well. By contrast, the average Ontarian where nuclear is a major source of electricity, believes nuclear is both safe and economically beneficial.
3. Respondents with a good general knowledge of nuclear technology or experience with nuclear technology were more likely to have a favourable opinion of nuclear energy.
4. There was no indication that the year long publicity campaign had altered Canadian's attitudes toward nuclear.

In 2019 Abacus Data undertook another survey for CNA. Rather than simply ask people what their attitude was toward nuclear energy, Abacus also questioned people about their level of concern about climate change and the need to transition to low emission energy sources. Abacus also provided respondents with information on the new reactor technology and SMRs in particular. Under this approach, the results were much more favourable to nuclear energy. More than 80% of respondents were concerned about climate change and expressed the need for Canada to reduce its use of fossil fuels. These concerns cut across generational and party lines although only 75% of people supporting the Conservative Party and residents of Alberta had the same concerns. The survey included questions that tested the public's knowledge of the carbon emissions associated with different energy technology and only 38% understood that nuclear energy had low GHG emissions relative to oil. Once informed about this difference respondents significantly increased their favourable opinion of nuclear to 49% and an additional 35% said they would be open to considering nuclear. When informed about SMR technology and how it might be deployed, 86% said they would be open to considering or supportive of such technology.

This survey generated results much more favourable to further nuclear development, especially deployment of SMR technology. However, the survey could also be criticized as "leading" respondents to a favourable opinion of nuclear in general and SMR in particular. As there is no experience anywhere with Gen IV SMR technology any expression of a favourable opinion can only be based on technological expectation not real experience with the technology.

Anti-nuclear public interest groups are well organized in Canada and are likely to oppose any new nuclear energy proposals. To get an idea of the extent of public opposition to nuclear in Canada see public comments on the proposed SMR to be constructed at Chalk River: https://ceaa-acee.gc.ca/050/evaluations/proj/80182/contributions?searchString=From+Kelly+Clune+to+The+Canadian+Nuclear+Safety+Commission+re%253A+Co mments+on+the+Project+Description+for+the+Micro+Modular+Reactor+Project+at+Chalk+River&action=search&projectID=80182&consultationPeriodId=&wbdisable=true

Canada's government, however, appears to be on board. The minister of Natural Resources has stated that nuclear innovation will play “a critical role” in reducing greenhouse gas emissions as Canada moves toward a low-carbon future. The Nuclear Roadmap consultation has identified regions of Canada that are more positive toward nuclear. The government sees SMRs as the technology to provide carbon free energy to industry, to reduce carbon emissions from the Tar Sands, and to power remote communities, particularly indigenous communities. Indigenous communities will likely need much higher level of consultation if they are to become comfortable with having a SMR in or near their community. However, the government insists that no community will be forced to accept a reactor.

Three Canadian provinces (Saskatchewan, Ontario, New Brunswick) have announced that they plan to explore the new nuclear technology as a way to fight climate change. The three premiers have signed a Memorandum of Understanding to collaborate on the development and deployment of SMRs. On the other hand, three provinces (British Columbia, Quebec, Nova Scotia) have banned the mining of uranium.

Identifying pros and cons regarding public opinion depends on whether one is thinking favourably or unfavourably about nuclear energy. Below I have assumed a neutral to favourable opinion of nuclear in identifying pros and cons.

Pros: Public acceptance of nuclear energy from SMRs can apparently be increased by ensuring that the public is well informed about the technology and its potential benefits, particularly the fact that that power generated by an operating reactor is emissions free. Ontario has the highest number of nuclear reactors in Canada and people living near those reactors are generally quite positive about nuclear energy. The Federal and some Provincial governments are promoting nuclear power as part of the solution to Canada’s GHG emissions and are prepared to invest in new nuclear technology.

Cons: The anti-nuclear lobby in Canada is well funded and appears very firm in its opposition to nuclear energy under any circumstances. Many members of the public have an existential fear of nuclear energy, probably stemming from the history of isotope contamination from nuclear testing, the conditioning we all received about nuclear holocaust during the cold war, and serious if infrequent accidents at nuclear power facilities. This means nuclear will be a hard sell in many communities. First nations, in particular, have expressed grave concerns about nuclear energy. Nevertheless, the federal government list providing power to indigenous communities as one of the benefits of SMRs.

4. Need for more nuclear in Canada:

Political rhetoric aside, Canada is very much a laggard in addressing its GHG emissions. Among industrialized countries Canada ranks 3rd in GHG emissions per capita, exceeded only by the US and Australia (Saudi Arabia and Kazhakstan have higher per capita emissions). According to the conference board of Canada, Canada's per capita emissions in 2018 were 15.32 tons compared with 5.62 tons/capita in Great Britain and 5.19 tons/capita in France (both with populations about 2X Canada's) and 5.44 tons/capita in Sweden (with a population about 1/3 Canada's). The largest fraction of Canada's emissions come from the oil and gas industry (27%) followed closely by transportation (24%), which together produce more than 50% of emissions. Canada is not on track to achieve the GHG reductions it pledged under the 2015 Paris Accord, and has no credible roadmap for reaching net zero by 2050[1]. Having dragged its feet for so long, Canada will have to pull out all the stops to do its part in combatting climate change. The question is, should nuclear be a part of the solution?

In a recent report, the International Energy Agency points out that achieving the CO2 emissions reductions required to satisfy the Paris Agreement will require large increases in efficiency of energy use and major investment in renewable energy, as well as an increase in nuclear energy. But does this mean we need an increase in nuclear energy in Canada? We might be better advised to exploit our significant potential for solar, wind, and geothermal. Geothermal, in particular, is a proven technology in use in various countries (most notably the US) and like nuclear is baseload. Canada has large geothermal potential, but that potential has been largely ignored (although several small projects are currently in development). Canada might also be better advised to improve its infrastructure for electricity transmission between provinces. Since SMRs are not yet proven technology it seems imprudent to count on them to help much with GHG emissions reductions at least for the next few decades.

Pros: Nuclear power plants produce no emissions during operation. However, emissions do occur because of site preparation, construction materials, transportation of modules and fuel. Decommissioning will also involve GHG emissions. All energy sources have these pre- and post-project emissions that are typically not counted in their carbon footprint. Nuclear energy is the most concentrated form of known energy and small amounts of fuel can generate reliable energy for decades. Assuming SMRs technology lives up to its promise, SMRs are flexible in terms of size and output, and can be designed and optimized for specific purposes. However, modular manufacturing costs are only small if factories crank out parts for only one design. Linking small individual units to make a larger unit is part of being modular and may partially

[1] The recently tabled Canadian Net-Zero Emissions Accountability Act is an important step in the right direction but does not actually establish a plan to reach net-zero emissions.

offset the fact that no individual module is optimized for the energy task to be addressed. At least some SMRs can burn nuclear waste from large reactors thereby rendering it less hazardous. SMRs could be an opportunity for economic growth both domestically and internationally but this will depend on the results of several decades of development and deployment. Addressing climate change will likely require aggressive deployment of all available low emission energy sources. The promised flexibility of SMRs, their potential capability to deliver electricity, heat, and/or hydrogen will make them a valuable component of the new energy economy. Nuclear power is baseload, continuously produced, compared with wind and solar that are intermittent. Hydro and geothermal, however, are also baseload.

Cons: SMRs are still in the research and testing stage and are unlikely to be commercially viable for some time. The earliest any SMR could be put into service is 2030 but it is likely to be much later. With climate change moving rapidly towards the point of no return, time is of the essence and SMRs are not yet ready to contribute to the energy transformation. There is a risk that devoting resources (financial, human) to developing SMRs will detract from the needed aggressive deployment of other renewable technologies.

5. Projected costs versus the benefits of SMRs

Inside and outside Canada, construction of nuclear power plants has been plagued by excessive cost overruns. Nevertheless, once completed and operating, nuclear plants run at relatively low cost. For the Ontario CANDU plants, cost of electricity generation to the present time (including capital costs, repairs, operation, etc.) has been between 5 and 8 cents per KWH.

Components of a standard SMR design can be produced in a centralized factory and shipped to the installation location. This should greatly reduce the cost of the SMR. However, it is not possible say what the costs will really be until a number have been built. For the economic benefits of centralized production to be realized there will have to be agreement on a standardized SMR design. Regardless, SMRs will likely be expensive, in terms of cost per MW, at least in the beginning. Economic assessments of SMR technology uses installation costs of >$8000/kw compared with costs of $1786/kw for traditional fossil fuel plants. However, proponents point out that wind and solar were also expensive sources of electric power early in their deployment and they are now cheaper than coal. It is expected that, with experience, SMRs will become less expensive to install and operate. Power from SMRs is also expected to be 15% to 70% more costly than power from a traditional large reactor.

Nuclear reactors typically have a high capacity factor, which implies that they produce close to their rated energy production capacity. If a generator has a capacity of 500 kw it means that the generator can produce 500 kw continuously running at maximum safe speed. If, because of maintenance shutdowns, breakdowns, etc. the generator produces an average of only 300 kw then its capacity factor is (300/500) or 60% if expressed as a percentage. In the US, nuclear generators have a capacity factor of 93.5%. The next most reliable energy source is geothermal with a capacity factor of 74.4%. By comparison, wind has a capacity factor of 34.8% and solar has a capacity of 24.5%. Canada's nuclear reactors have not had quite as high a capacity factor as the US ones. For the first 25 years of operating life the CANDU reactors had capacity factors >80%. After 25 years, however, capacity began to drop off. However, they were still much better than solar or wind. Despite their high capacity factor, more than 1/3 of US nuclear plants are unprofitable and scheduled to close.

Estimated construction costs for Russia's floating nuclear power plant (with two 35-MW ice-breaker-type reactors) have increased more than four-fold since construction began, and now equate to over US$10 billion/gigawatt (GW). A 2016 OECD Nuclear Energy Agency report said that electricity produced by the plant is expected to cost about US$ 200/MWh, with the high cost due to large staffing requirements, high fuel costs, and resources required to maintain the barge and coastal infrastructure.

A 2016 report said that the estimated construction cost of China's demonstration HTGR (High Temperature Gas Cooled Reactor) is about US$5,000/kW – about twice the initial cost estimates. Cost increases resulted from higher material and component costs, increased labour costs, and project delays. The World Nuclear Association states that the cost of the Chinese HTGR is US$6,000/kW.

The CAREM (Central Argentina de Elementos Modulares) SMR under construction in Argentina illustrates the gap between SMR rhetoric and reality. In 2004, when the CAREM reactor was in the planning stage, Argentina's Bariloche Atomic Center estimated an overnight cost of US$1 billion/GW for an integrated 300-MW plant. When construction began in 2014, the estimated cost was US$17.8 billion/GW. By April 2017, the cost estimate had increased to US$21.9 billion/GW. The CAREM project is years behind schedule and costs will likely increase further. In 2014, first fuel loading was expected in 2017 but completion is now anticipated in November 2021.

A 2015 report by the IEA and the OECD NEA predicts that electricity costs from SMRs will typically be 50−100% higher than for current large reactors, although it holds out some hope that large volume production of SMRs could reduce costs − if that large volume production is comprised of "a sufficiently large number of identical SMR designs".

A South Australian Royal Commission identified hurdles and uncertainties facing development and commercial deployment of SMRs including the following:

- SMRs have a relatively small electrical output, yet some costs including staffing may not decrease in proportion to the decreased output;
- SMRs have lower thermal efficiency than large reactors, which generally translates to higher fuel consumption and spent fuel volumes over the life of a reactor;
- SMR-specific safety analyses need to be undertaken to demonstrate their robustness, for example during seismic events;
- It is claimed that much of the SMR plant can be fabricated in a factory environment and transported to site for construction. However, it would be expensive to set up this facility and it would require multiple customers to commit to purchasing SMR plants to justify the investment;
- Reduced safety exclusion zones for small reactors have yet to be confirmed by regulators;
- Timescales and costs associated with the licensing process are still to be established; and
- Customers who are willing to take on first-of-a-kind technology risks must be secured.

Clearly, there remain many uncertainties about the cost of building a commercial SMR and whether the expected benefits that will mitigate the high cost of the first few reactors will actually materialize. However, many of the economic analyses compare SMRs against cost of coal and gas fired electricity generation. If we are to address the climate crisis, we have to set fossil fuel generation aside and nuclear may be the only viable, if expensive, option in some circumstances. The high cost of nuclear energy will require that governments support the deployment of SMRs for some time.

Pros: Individual reactor cost should be much less than for a large reactor making financing much easier for most jurisdictions. Given the imperative to stop using fossil fuels, having viable nuclear technology could help fill the energy gap.

Cons: Actual construction and operating costs are uncertain and projects currently under construction are experiencing large cost overruns. There is agreement that SMR costs, at least during the first years of implementation, will be high and electricity costs much higher than existing fossil fuel plants. Developing the industrial infrastructure for SMRs and deploying them in Canada will require at least short term and possibly long term government support.

6. Safety of SMRs

Following the 2011 Fukushima accident, the Canadian Nuclear Safety Commission (CNSC) ordered all reactor operators to revisit their safety plans and report on potential improvements by the end of April 2011. The International Atomic Energy Agency (IAEA) later conducted a review of the CNSC's response to the Fukushima accident and concluded that it was "prompt, robust and comprehensive”, and was a model that other regulatory bodies should follow. This endorsement of the CNSC is important because in other contexts the regulatory agency has been accused of being captive to the nuclear industry.

Nuclear reactors do contribute to an increase in radiation in the vicinity of the plant, but this increase is small relative to background radiation and smaller than the radiation released into the environment by a typical coal fired plant. The CNSC conducted an 18 year study (1990 – 2008) of cancer incidence within a 25 km radius of Ontario's three nuclear power plants and found no consistent differences in the overall incidence of cancer from that in the general public. Spent radioactive fuel is currently stored on site at Canadian reactors and to date no incidence of human health effects from the stored nuclear waste have been recorded.

Since there are no SMRs there are no studies of any radiation releases from them. However, SMRs have good safety features including:

- a convective cooling mechanism that will continue to function if external power is lost, making core meltdown virtually impossible;
- SME reactor cores are small and produce much less heat, further reducing the risk of any meltdown;
- Many SMR designs are integral, which means that fuel, coolant, and steam producing system are all within a single vessel, further reducing the number of component parts that could suffer breakdown;
- SMRs typically operate at low pressure, further reducing the potential for an uncontrolled leak of radioactive materials; and
- SMRs could be constructed underground, so that any release of radioactive materials would be limited to the reactor site. An underground location would also provide greater security and protection from certain natural hazards.

As yet, no comprehensive safety guide for SMR construction and operation has been developed. Canada is at the forefront of a small number of nations (including Russia, China, Argentina) currently developing technology-neutral regulatory frameworks for SMR installation, operation, and decommissioning based on IAEA safety standards. Because SMRs come in various designs, the "technology-neutral" feature is to enable novelty and innovation in reactor design, construction, operation and decommissioning, without compromising safety.

Should Canada proceed to the stage of siting and constructing SMRs, the CNSC will be responsible for organizing and overseeing any environmental and social impact assessments of the project. This concerns opponents of nuclear energy who believe the CNSC is in the thrall of the nuclear industry

The safety of the reactor itself is, of course, only part of the safety concerns around nuclear energy. Concern also attends the mining and processing of uranium ore, the transport and storage of fissionable materials, the manufacture, transport, and storage of reactor fuels, and the storage and disposal of spent fuel. These all fall within the regulatory responsibility of the CNSC.

Canada has abundant and relatively rich deposits of uranium ore and a long history of mining and processing uranium ores to contribute to the nuclear weapons industry (during WW II) and to produce nuclear reactor fuel. Uranium mining has occurred in the Northwest Territories, northern Saskatchewan and various locations in Ontario. Presently, the only operating mines are in northern Saskatchewan. Canada is a major international producer of uranium and 90% of what is produced is exported. Three provinces (BC, Quebec, Nova Scotia) have banned the mining of uranium.

The CNSC licenses and regulates all uranium mining and milling operations in Canada and manages the industry to ensure compliance with the Nuclear Safety and Control Act (NSCA). The NSCA is, itself, consistent with international safety standards in accordance with Canada's international obligations for safe use of nuclear materials. Radiation exposure of workers at a mine site must be monitored to prevent unsafe exposure to radiation. When a mine is decommissioned tailings and other waste must be buried underground in such a way that it will not pose a risk to the public or to the environment.

In 2002, Canada passed the Nuclear Fuel Waste Act (NFWA), which makes the nuclear industry responsible for developing an approach and a plan for long-term waste management. In accordance with the legislation, the industry established the Nuclear Waste Management Organization (NWMO), which has assumed responsibility for the safe management and storage of nuclear waste, including both short term "on site" storage and long term deep geological repositories.

Canada, like other countries that utilize nuclear energy, has struggled with what to do with nuclear waste. With no long term solution, nuclear waste has been stored on site at nuclear facilities in sealed containers. To date, there are no examples of nuclear waste ever harming someone in Canada, but a long-term solution to nuclear waste must be found. A deep geological repository is considered the best long-term solution. Since 2010 the NWMA has consultated with communities and has conducted geological evaluation in communities that indicated a willingness to accept a deep geological repository. Detailed geological evaluation is underway in two communities in Ontario (South Bruce in southern Ontario and St Ignace in northwestern Ontario). Individuals and organizations opposed to nuclear energy continue to agitate against locating repositories in these communities.

The government of Canada (AECL) created "Canadian Nuclear Laboratories" in 2014 to deliver Canada's nuclear programs, including waste management. The operation of CNR has been contracted to a consortium of private companies in 2015. This consortium includes SNC-Lavalin, which is a source of concern for opponents of nuclear. Anti-nuclear groups also claim that the CNSC is a "captured regulator", overly friendly to the nuclear industry. The principal evidence they bring forward in support of this claim is that CNSC has never refused an application from the nuclear industry.

Pros: Canada has a long history of utilizing nuclear energy with a good safety record. Federal legislation governs all extraction, processing, use, and disposal of uranium and its products in Canada so that there is no patchwork of different provincial regulations. Canada conforms to the safety standards set by the International Atomic Energy Agency. Canada is in the process of establishing a deep geological repository for long lived nuclear waste, one of the first countries to do so. Canada is also in the process of developing SMR technology that, on paper at least, is safer, more flexible, and lower cost (per reactor unit) than existing large nuclear reactors.

Cons: All stages of the nuclear energy process, from mining to waste disposal, pose a risk of leakage of nuclear materials and radiation into the environment. There is no way to make this risk zero, however, setting aside some issues early in Canada's nuclear history, Canada has a good record of safe use of nuclear materials and energy. As I have frequently noted, all SMR designs are still in the development and testing stage so that final evaluation of their actual safety is not yet possible. The contracting of Canada's nuclear operations to a private consortium including SNC-Lavalin is viewed with concern by anti-nuclear groups.