Canada's mixed nuclear policy experiences

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> In 1954, the silence of the forest was broken by prospectors in search of a new prize: uranium, the mineral whose mysterious power was the key to a new age.

— *A City is Born*, Ontario provincial government film about uranium mining at Elliot Lake[1]

> Sir Humphrey Appleby: Then there's the excuse we used for Concorde, it was a worthwhile experiment, now abandoned, but not before it had provided much valuable data and considerable employment.
>
> Minister Jim Hacker: But that is true isn't it? Oh no, of course it isn't.

— "A Question of Loyalty", *Yes, Minister*[2]

After the Second World War, when the world as a whole was coming to appreciate the civilian possibilities associated with nuclear fission, Canada's government committed itself to developing substantial domestic nuclear capabilities. This commitment included basic research, including for reactor design and development; the design and construction of commercial nuclear reactors; attempts at exporting reactor designs; the development of uranium mining, milling, and enrichment; and the use of nuclear expertise for other purposes, notably the production of medically-useful isotopes. The letters patent which established Atomic Energy of Canada Limited (AECL) in 1952 embodied Canada's ambition to "develop the peaceful uses of Atomic Energy for the benefit of all Canadians".[3] Because Canada's nuclear policy has involved multiple objectives in quite widely-separated fields, it may not be appropriate to evaluate its success or failure when taken all together. Furthermore, the development of Canadian nuclear capabilities has taken place in front of a backdrop of other substantial societal changes. For instance, concern about carbon dioxide (CO_2) emissions was essentially absent when Canada decided to develop domestic nuclear power capabilities, but this aspect of nuclear power has become highly salient more recently.[4] In the face of these complexities, the observations of Bovens *et al.* about policy evaluation are worth bearing in mind. They argue that:

> even the most neutral, professional evaluators with no political agenda of their own are likely to become both an object and, unwittingly or not, an agent of political tactics of framing, blaming, and credit claiming.[5]

[1] The Province of Ontario, *A City is Born — The Story of Elliot Lake*.
[2] Jay and Lynn, *Yes, Minister. Series 2. Episode 7. "A Question of Loyalty"*.
[3] Krenz, *Deep Waters: The Ottawa River and Canada's Nuclear Adventure*, p. 114.
[4] See: Ilnyckyj, "Climate Change, Energy Security, and Nuclear Power".
[5] Bovens, Hart, and Kuipers, "The Politics of Policy Evaluation".

As Turnpenny *et al.* identify, "policy appraisal is undoubtedly an important site of political behaviour, with its own institutions, instruments and policy actors".[6] Both proponents and opponents of Canada's nuclear policy make use of such strategies, and observers attempting to be fair-minded must deal with many issues of non-comparability (how to balance the risk of accidents against the absence of air pollution, or climate benefits against nuclear waste dangers?). All this limits the degree to which we can reach unambiguous conclusions about policy efficacy in this field.

In addition to being interesting and important in itself, the example of Canada's nuclear policy may be useful for refining our thinking about what policy success or failure means. Several different interpretations can be readily identified, including correspondence between the stated aims of policy-makers at the outset and the observed outcomes of a policy, resolution of the 'problem' the policy was intended to address, and the public perception that a policy has been successful — either while it is ongoing or upon reflection after the fact.[7] Howlett provides a set of conceptualizations for policy evaluation that includes success in terms of original goals, in terms of support and opposition, in terms of innovation, and across other axes.[8] The nuclear example can be evaluated through any of these lenses, but it also reveals how complex and contingent the identification of policy success or failure may be, particularly for multidimensional policies applied over a long period of time. There is by no means universal agreement on the proper interpretation of Canada's nuclear experience. Nonetheless, it is possible to identify areas where a stronger claim to success can be made (such as developing and maintaining a position as a major global uranium supplier) and others where policy ambitions have probably not been met (such as becoming a major exporter of reactor designs). In the nuclear area, as in Canada's economic history generally, our role has arguably been more to supply large quantities of raw materials to others rather than to develop and disseminate technologies internationally.

[6]Turnpenny et al., "The Policy and Politics of Policy Appraisal. Emerging Trends and New Directions", p. 640.

[7]The degree to which a policy achieved its initial outcomes may be a deeply problematic measure of success in cases where there have been major normative changes within society since the policy was developed. For instance, policies intended to assimilate French Canadians or Canadian aboriginals may now appear loathsome to us in their "success".

[8]See: Howlett, "The lessons of failure: learning and blame avoidance in public policy-making", p. 542.

1 | The CANDU design

The particularities of the Canada Deuterium Uranium (CANDU) style of reactor illustrate many of the dimensions of Canada's choice to develop domestic nuclear expertise. Specifically, they illustrate nuclear energy as part of a broader industrial policy in which Canada's existing manufacturing capabilities would be put to use to harness the new energy source. Whereas the nuclear reactors built by American and Japanese companies make use of a single large pressure vessel, the construction of such vessels was beyond Canadian capabilities. Instead, each CANDU reactor contains hundreds of smaller pressure tubes inside a calandria structure.[9] For Canada's early reactors, these tubes were built by the Dominion Bridge Company of Montreal. The CANDU design is also unusual in its choice of heavy water as a neutron moderator — the medium incorporated into the core of a nuclear reactor to slow 'fast' neutrons which do not efficiently induce fission in uranium into 'thermal' neutrons, which effectively sustain the nuclear chain reaction. Most of the world's commercial nuclear power plants are 'light water' reactors: pressurized or boiling water reactors that use ordinary water as a moderator and therefore require enriched uranium to function. The heavy water design permits the use of a broad range of fuels, including un-enriched 'natural' uranium.[10] [11] Canada's first heavy water was produced in 1943 by the Consolidated Mining and Smelting Company in Trail, British Columbia. Due to the difficulty of separating deuterium-bearing water molecules from those endowed only with the most common isotope of hydrogen, heavy water is costly. The moderator embodied nearly 30% of the capital cost for the Darlington Nuclear Generating Station.[12] CANDU reactors are designed to function for 60 years, with an extended shutdown at mid-life to replace the fuel channels.[13][14][15]

[9] One advantage of this design, when compared with light water reactors, is the ability to refuel at power, rather than requiring reactor shutdown to do so.

[10] Angus and Mitchell, *Attention Canada! Preparing for our Energy Future: Seventh report of the Standing Senate Committee on Energy, the Environment and Natural Resources*, p. 27.

[11] At one point, this design choice may have seemed an important match for Canada's large reserves of uranium, but it is arguably less important now that Canada undertakes a significant fraction of the world's uranium enrichment, including the fabrication of fuel for light water reactors elsewhere.

[12] Ontario Power Generation, *Final and Total Capital Cost of the Darlington Nuclear Generating Station*.

[13] This process has been undertaken as a routine procedure at the Wolsong station in South Korea. The reactor was built between 1977 and 1983 and re-tubed between 2006 and 2011. Re-tubings have also been carried out in Canada for units 1 and 2 at the Bruce Station, and the Point Lepreau station. Nuclear Engineering International, *Wolsong 1 retubed*.

[14] See also: Candu Energy Inc. *Wolsong*.

[15] Candu Energy Inc. *CANDU History*.

The development and operation of CANDU reactors have been consistently supported by Canadian federal and provincial governments. In 1952, the federal government established Atomic Energy of Canada Limited (AECL) as a Crown corporation, providing the company with property, plant, and other assets in exchange for an equity stake.[16] In its early years, AECL received annual federal funding of about $20 million.[17] Over the past 60 years, Canadian taxpayers have provided support for AECL in a variety of forms, including funding research and development at AECL's Chalk River laboratories, supporting the development of CANDU and other reactor designs, absorbing costs for legacy wastes and liabilities, providing limitations on liability for accidents, and furnishing financial support for CANDU exports (including loans and loan guarantees).[18] AECL Research, the branch charged with developing a Canadian nuclear reactor, was 90% funded by the federal parliament, up to 1980.[19] In total, one estimate of federal subsidies to AECL up to 2006 added to $74.9 billion — equivalent to 12% of Canada's national debt at the time.[20] In 2009, a spokesperson for Prime Minister Stephen Harper estimated total federal subsidies to AECL at $30 billion.[21] Another estimate of just the inflation-adjusting funding provided for reactor development is $15.2 billion.[22] The sheer range of these estimates illuminates the major challenge of evaluating the cost-effectiveness of Canada's nuclear policies.[23] Provinces also provide taxpayer support to the industry. The Ontario government covered a portion of the cost overruns from reactor refurbishments in the 1990s, while the governments of Quebec and New Brunswick have borne costs from the Gentilly and Point Lepreau stations.

The path to a commercial Canadian-designed reactor involved many preliminary steps.[24][25] Led by Wilfred Bennett Lewis, these efforts included designing and building the NRX and National Research Universal

[16] Balls, "The Financial Control and Accountability of Canadian Crown Corporations", p. 137.

[17] Sovacool and Valentine, *The National Politics of Nuclear Power: Economics, Security, and Governance*, p. 179.

[18] Doern and Morrison, *Canada's Nuclear Crossroads: Steps to a Viable Nuclear Energy Industry*, p. 6.

[19] Hurst, *Canada Enters the Nuclear Age: a technical history of Atomic Energy of Canada Limited as seen from its research laboratories*, p. 36.

[20] Adams, *Federal Government Subsidies to Atomic Energy of Canada Limited*, p. 2.

[21] The Economist, *Ending a dream, or nightmare*.

[22] Sovacool and Valentine, *The National Politics of Nuclear Power: Economics, Security, and Governance*, p. 179.

[23] Notably, Turnpenny *et al.* argue that the economic aspects of policy are often focused on to the extent of 'crowding out' the assessment of social and environmental impacts. If there is deep uncertainty on even the economics of Canada's nuclear policy, it raises questions about the feasibility of evaluating its success or failure in any meaningful way. Turnpenny et al., "The Policy and Politics of Policy Appraisal. Emerging Trends and New Directions", p. 643.

[24] AECL wasn't the only entity involved in this work. Ontario Hydro was to function as plant operator; Canadian General Electric actually built the Nuclear Power Demonstration; and the Eldorado Nuclear corporation provided uranium.

[25] For a more detailed history of Ontario's nuclear facilities, see: Ilnyckyj, *Climate change and nuclear power in Ontario*.

Reactor (NRU) research reactors at Chalk River, constructed in 1947 and 1957, respectively.[26] [27] The design, construction, and operation of these reactors provided expertise in materials and technologies for the eventual deployment of commercial nuclear power plants.[28][29] These research reactors were followed by the 22 megawatt Nuclear Power Demonstration and 200 megawatt Douglas Point Nuclear Generating Station, which was intended to serve as Canada's first commercially viable nuclear facility.[30] Canada's operation of a truly commercially viable nuclear generating station began when the first four reactors at Pickering went online in 1971 (four more started up in 1983). These provided the experience necessary to complete the CANDU 6 design installed at Gentilly-2 in Quebec and New Brunswick's Point Lepreau station. The Bruce complex, which is now the second most powerful nuclear station in the world, was constructed in phases starting in 1969 and 1977. Darlington was Canada's last major nuclear undertaking, built between 1981 and 1993. Canada now has an operational fleet of 19 CANDU reactors, along with an active debate — federally and in Ontario — about whether to refurbish or replace any of them.

Canada's experience with commercial nuclear power stations has involved costly incidents and construction price over-runs. Both the initial construction and subsequent retrofits of Canadian nuclear reactors have exceeded budgetary estimates, even before accounting for some of the indirect subsidies received by the industry. For example, a reactor refurbishment at Pickering that was meant to be complete by 2000 at a cost of $780 million actually took until 2003 and cost $1.25 billion.[31] The construction of the four Pickering B reactors — estimated in 1974 at $1.6 billion — ended up costing $3.8 billion.[32] The refurbishment of Point Lepreau similarly ran three years and $1 billion beyond expectations.[33] When approved in 1978, it was expected that the Darlington nuclear station would cost $2.5 billion; in the end, it was completed a decade late at a cost of $14 billion.[34] This cost overrun drove the Ontario Government to split Ontario Hydro into five

[26]See: Fawcett, *Nuclear pursuits: the scientific biography of Wilfrid Bennett Lewis*.

[27]Notably, the NRX reactor experienced a partial meltdown in 1952.

[28]For instance, the core of the NRU reactor was designed to be able to replicate the conditions that would be found inside a commercial reactor, allowing for the testing of reactor core materials.

[29]See: Lovell and Hurst, "Wilfred Bennett Lewis. 24 June 1908 — 10 January 1987", p. 487.

[30]Ibid., p. 490.

[31]Winfield, *Blue-Green Province: The Environment and the Political Economy of Ontario*, p. 140.

[32]Ibid., p. 106.

[33]Dubinsky, *AECL woes could spell end of Canada's reactor business*.

[34]Cadham, *The Canadian Nuclear Industry: Status and Prospects*, p. 5.

Crown corporations, and take on $38 billion in debt retirement charges which are still being paid through the electricity bills of Ontario consumers.[35] After a 1983 pressure tube failure at Pickering, all of the pressure tubes in the Pickering A reactors had to be replaced at a cost estimated by the Pembina Institute at $2.5 billion.[36] This Scale Fuel Channel Replacement cost significantly more than the $718 million expense of building the four Pickering A reactors in the first place.[37] Involvement with past nuclear projects can also create expensive future liabilities for governments; the New Brunswick provincial government is seeking $1 billion in compensation from the federal government, for costs associated with the Point Lepreau cost overruns.[38]

The Gentilly Nuclear Generating Station Bécancour, Quebec is worthy of special consideration. Gentilly-1, an attempted simplification of the CANDU design, was a notable failure that functioned for only 180 days over seven years before being shut down.[39] Gentilly-2 is a 675 megawatt CANDU 6 reactor, similar to those Canada later exported to South Korea, Argentina, Romania, and China. In 2012, it was shut down, following a decision not to refurbish the plant, which had a projected cost of $4.3 billion.[40] Instead, the plant was to be decommissioned over an 18 month period. Preliminary plans for a Gentilly-3 expansion were cancelled by Quebec Premier René Lévesque in 2012.[41]

Canada's aspiration to export reactors arose early in its process of nuclear development. Duplicates of the early Douglas Point reactor were built in India and Pakistan. Canada's aspiration to develop nuclear power stations using its limited domestic manufacturing capability arguably added to the export appeal of the designs, since potential customers would likely face similar limitations and would likely see appeal in reactor designs that could be built to the greatest possible degree using their domestic capabilities. The first international CANDU reactor to come online was Rajasthan-1 in India, in 1972.[42] In the end, Canada exported nuclear reactors to India, Pakistan, Taiwan, Argentina, South Korea, Romania, and China.[43] These were not all CANDU-style

[35] Ibid., p. 6.

[36] Winfield, Horne, and Peters, *Power for the Future: Towards A Sustainable Electricity System for Ontario — Appendix 2 Ontario's Nuclear Generating Facilities: A History and Estimate of Unit Lifetimes and Refurbishment Costs*, p. 127.

[37] Ibid., p. 106.

[38] CBC News, *AECL sold for $15M to SNC-Lavalin*.

[39] Cadham, *The Canadian Nuclear Industry: Status and Prospects*, p. 5.

[40] CBC News, *Quebec's Gentilly-2 nuclear plant shuts down after 29 years*.

[41] Brousseau-Pouliot, *Les enjeux oubliés de la campagne*.

[42] Canadian Nuclear Association, *The Canadian Nuclear Factbook 2013*, p.6.

[43] Bratt, "Candu or candon't: Competing values behind Canada's nuclear sales", p. 2.

electricity reactors, but also include research reactors. As of 1997, Canada's share of the nuclear export market was about 11%, not including reactors that were then still under construction.[44]

Writing in the *Nonproliferation Review*, Duane Bratt argues that Canada's export policy for reactors contradicted another important Canadian policy goal.[45] Specifically, Bratt argues that Canada's support for the global non-proliferation regime for nuclear weapons is at odds with "its export of proliferation-risky" reactors. The concern that nuclear technology exported from Canada will be used for nuclear weapon development is not hypothetical. India's first nuclear test in 1974 is thought to have used nuclear material bred in the CIRUS research reactor Canada sold in 1956.[46] While Canada's supply agreement with India required that the reactor be used for "peaceful" purposes, the Indian government has interpreted providing material for "peaceful nuclear explosives" to be permissible.[47][48][49] India has also modeled a second reactor after the Canadian-exported one, for use in further plutonium production. Even outside the context of supplying nuclear weapons, this case illustrates a challenge with CANDU exports: namely, how countries that have purchased some reactors from Canada have gone on to build subsequent CANDU-derived facilities without Canadian participation. Once acquired, the nuclear capabilities of a state are not easily restricted. By providing reactor technology to both India and Pakistan, Canada has likely contributed to what is arguably the most threatening nuclear rivalry in the world today, with the frightening possibility of conventional war escalating to the use of nuclear weapons, or the accidental or unauthorized use of weapons by either party. As highlighted by Cooke, reactor-exporting states including Canada, France, and the United States have often been driven by profit-seeking and policy-justification reasons to export materials and technologies that carried a high risk of contributing to weapon proliferation.[50] [51]

The recent history of AECL establishes the context for today's nuclear policy-making in Canada. In an anal-

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[44] Ibid., p. 4.

[45] Ibid.

[46] Cooke, *In Mortal Hands: A Cautionary History of the Nuclear Age*, p. 114.

[47] Albright, "The shots heard 'round the world".

[48] See also: Perkovich, *India's Nuclear Bomb: The Impact on Global Proliferation*, p. 71, 159.

[49] Lovell and Hurst, "Wilfred Bennett Lewis. 24 June 1908 — 10 January 1987", p. 498.

[50] Cooke, *In Mortal Hands: A Cautionary History of the Nuclear Age*.

[51] Cooke also accuses nuclear regulators of having experienced regulatory capture, particularly when the same national institutions are charged with maintaining safety and with promoting reactor sales abroad and maintaining domestic support for nuclear power.

ysis conducted for the C.D. Howe Institute, three key factors were identified for assessing the future viability of Canada's nuclear power industry: cost, the status of AECL, and regulation.[52] The authors concluded that nuclear energy stands to be cost-competitive with fossil fuels, once the externalities associated with fossil fuel use are considered. They called for the partial privatization of AECL, continued funding for basic research and development, and a review of Canada's nuclear regulatory processes. Analyses like this, which highlight the potential for a revitalized and more fully privatized Canadian nuclear industry have accompanied diminished enthusiasm from the federal government to bankroll and support domestic nuclear technology development. In particular, political willingness to subsidize AECL has waned in recent years. After 1985, federal government funding for reactor development at AECL was significantly reduced, while the Crown corporation was encouraged to develop a more commercial approach to technological development.[53] Despite the hope of reducing taxpayer reliance, challenges faced by AECL and a continuing effort to develop and promote an 'Advanced CANDU reactor' have meant that governmental outlays have continued. Between 2006 and 2009, federal subsidies to AECL amounted to $1.7 billion.[54]

In 2011, the federal government announced that AECL would be sold to the Montreal-based engineering group SNC-Lavalin for $15 million.[55][56] The immediate motivation for the sale was the desire to move beyond the recent experience of heavy federal subsidies to AECL, and perhaps to distance the federal government from recent difficulties experienced by the organization. These developments could provide scholarly opportunities to examine policy learning of the sort described by John in a complex policy area with an involved history, as well as for the study of blame avoidance among policy-makers.[57] While SNC-Lavalin intends to maintain a CANDU reactor division, and will continue to provide life-extension services at existing facilities, it remains unclear whether any further CANDU reactors will be built in Canada or elsewhere. The sale was interpreted by a number of media commenters as evidence that Canada was moving out of the reactor construction business.

[52] Doern and Morrison, *Canada's Nuclear Crossroads: Steps to a Viable Nuclear Energy Industry*.
[53] Hurst, *Canada Enters the Nuclear Age: a technical history of Atomic Energy of Canada Limited as seen from its research laboratories*, p. 37.
[54] The Economist, *Ending a dream, or nightmare*.
[55] CBC News, *AECL sold for $15M to SNC-Lavalin*.
[56] See also: World Nuclear News, *AECL's reactor business goes to SNC Lavalin*.
[57] John, *Analyzing Public Policy: Second Edition*, p. 130, 171.

It was accompanied by between 800 and 900 layoffs, accounting for somewhat less than half the staff.[58]

2 | Medical isotopes

In addition to their use in generating electricity, nuclear reactors can be used to fabricate unusual materials. The NRU reactor at Chalk River is used to produce medically-useful radioisotopes including cobalt-60 (used in radiation therapy), iodine-125, iodine-131, molybdenum-99, technetium-99 (used for diagnosis), and xenon-133, collectively used for both for imaging and treatment applications. Canada is the world's largest producer of medical isotopes.[59] Isotope production at the now-nearly-sixty-year-old NRU reactor precipitated the most dramatic confrontation in Canada's history between the elected government of the day and Canada's nuclear regulatory body, the Canadian Nuclear Safety Commission. A shutdown of the reactor in 2007 was extended in order to install more earthquake-resistant emergency power systems for the reactor's cooling pumps. The shutdown of the reactor led to worldwide shortages of short-lived isotopes that could not be produced elsewhere. In December of 2007, the House of Commons passed a resolution ordering the reactivation of the reactor with only a single cooling pump. This decision was publicly opposed by Linda Keen, President of the Canadian Nuclear Safety Commission, who was ultimately fired for "lack of leadership".[60][61][62] A second shutdown of the reactor in May 2009 (caused by a heavy water leak) lasted until August 2010, leading to another international shortage of medical isotopes.

Continued reliance on the NRU reactor itself represents a failure in the implementation of Canadian nuclear policy. As successors to the NRU, AECL attempted the development of two Multipurpose Applied Physics Lattice Experiment (MAPLE) reactors at Chalk River, intended specifically for the production of medical isotopes. The MAPLE reactors were completed eight years behind schedule, and at twice the projected cost of $350 million.[63] Even more problematically, the reactors never functioned as intended. After a great deal of controversy, the MAPLE reactors were cancelled in 2008, after AECL estimated that it would cost at

[58] CBC News, *AECL sold for $15M to SNC-Lavalin*.
[59] Canadian Nuclear Association, *The Canadian Nuclear Factbook 2013*, p. 4.
[60] CBC News, *Risk of restarting nuclear reactor too high: Keen*.
[61] CBC News, *Nuclear safety watchdog head fired for 'lack of leadership': minister*.
[62] CBC News, *Court upholds firing of nuclear safety watchdog head*.
[63] Dubinsky, *AECL woes could spell end of Canada's reactor business*.

least $1 billion to make them operate properly.[64] Most crucially, the reactors demonstrated an unexpected and undesirable positive power co-efficient of reactivity, meaning the amount of reactivity in the core of the reactors increased as their power output did, increasing the danger of their operation. In March 2014, the highly-enriched uranium targets which the MAPLE reactors were intended to use were returned to the United States.[65]

3 | Canada's uranium industry

Canada's rise to prominence as a major global uranium producer provides the most straightforward example of national capabilities being successfully developed, leading to a world-beating record. The Eldorado Gold Mining Company began extracting uranium from a mine in the Northwest Territories during WWII, with the intention of providing fissile material for the American nuclear weapon program.[66] The material was milled and refined at the company's facility in Port Hope, Ontario, which remains one of the world's most important sites for processing fissile materials. Now operating by the Cameco Corporation, the uranium conversion facility at Port Hope produces over 12,000 tonnes of uranium hexafluoride for enrichment each year along with 2,800 tonnes of uranium oxide for use as reactor fuel.[67][68] Port Hope operates as the second stage in Canada's uranium refining industry, processing uranium trioxide which is produced upstream from milled uranium ore at Blind River.[69]

Without question, Canada is one of the world's main producers of the raw materials for nuclear energy. Major Canadian uranium mines were developed after WWII, including near Uranium City, in Saskatchewan, and at Bancroft and Elliot Lake in Ontario. Later mines operated in Ontario and the Northwest Territories. Major mining operations currently take place in McArthur River, Rabbit Lake, the McClean Lake area, and the Cigar Lake area in Saskatchewan. Canada is the world's second largest producer of uranium, after Kaza-

[64] Ibid.

[65] MacLeod, *Uranium stockpile quietly exported back to U.S., Canada reveals*.

[66] Canadian Nuclear Safety Commission, *Canada's Historical Role in Developing Nuclear Weapons*.

[67] Cameco, *Port Hope — History / Innovations*.

[68] See also: Natural Resources Canada, *About Uranium*.

[69] Angus and Mitchell, *Attention Canada! Preparing for our Energy Future: Seventh report of the Standing Senate Committee on Energy, the Environment and Natural Resources*, p. 26.

khstan.[70] 80% of Canadian uranium production is exported, yielding about $1 billion per year.[71][72] Canadian mines supply about 20% of the world's uranium, with 14.5% of the world's supply coming from just the McArthur River mine in Saskatchewan.[73][74] Across history, more uranium has been mined from Canada than from any other country, amounting to 18% of the global total.[75] Several new mines are now planned or under construction, with the potential to significantly boost Canadian uranium exports.

While clearly successful from a commercial perspective, Canada's uranium mining and processing industries certainly have not escaped public criticism, including on grounds of causing local environmental contamination, contributing to the development of mass nuclear arsenals, and simply for providing the fuel stock for the eternally-controversial nuclear power industry.[76] That being said, at least some environmental advocates (with the enthusiastic support of the nuclear industry) defend nuclear power as a lesser evil, with claims about the toxic air pollution and greenhouse gas pollution avoided by using uranium fuel rather than coal, oil, or gas.

4 | Conclusions

Canada's nuclear experiences illustrate many nuances of policy evaluation. For instance, complex policy areas virtually always involve tensions between competing objectives, such as the desire to build electrical generating facilities at the lowest cost versus the desire to develop domestic industries, or the desire to minimize the proliferation of nuclear weapons versus the desire to export reactors and uranium. Citing earlier insights from Lindblom, Howlett explains that:

> a policy is often considered a success if it successfully navigates a complex, veto-point-filled and multi-actor approval process to creation and implementation, regardless of its actual ability to 'deliver-the-goods' in terms of its substantive programme effectiveness or efficiency.[77]

[70] Canadian Nuclear Association, *The Canadian Nuclear Factbook 2013*, p. 4.

[71] Angus and Mitchell, *Attention Canada! Preparing for our Energy Future: Seventh report of the Standing Senate Committee on Energy, the Environment and Natural Resources*, p. 26.

[72] Canadian Nuclear Association, *Nuclear Facts – Why is uranium important to Canada?*

[73] World Nuclear Association, *Uranium in Canada*.

[74] World Nuclear Association, *World Uranium Mining Production*.

[75] World Nuclear Association, *Uranium in Canada*.

[76] See: Mehta, *Risky Business: Nuclear Power and Public Protest in Canada*.

[77] See: Howlett, "The lessons of failure: learning and blame avoidance in public policy-making", p. 545-6.

To some degree, this analysis may be applicable to Canada's nuclear experience, in that Canada succeeded in developing extensive domestic nuclear capabilities, but did not achieve the degree of hoped-for benefit, success at the desired cost, or success within all areas of effort. This history has clearly involved "deficiencies" of the kind discussed by Kearns and Lawson.[78] Canada's nuclear history also involves many forms of path dependence, with each new government constrained by the enduring effects of policy decisions made by its predecessors. This dependency will continue in a very tangible way into the indefinite future, given the long-term requirement to decommission nuclear facilities, manage them indefinitely in a shut-down state, and deal with the many kinds of radioactive waste they generate.[79]

Nuclear energy brings to the forefront questions about the relationship between public opinion and policy success or failure. To what degree should public sentiment about nuclear power be taken as a measure of the success of Canada's nuclear policy, particularly in comparison with technical evaluations of success in relation to the concrete objectives of policies at the time of their announcement? It is entirely possible that a policy could appear successful in technical terms, while simultaneously seeming like a failure in terms of public opinion. In a 2012 telephone survey of 1,000 Canadians conducted on behalf of the Canadian Nuclear Association, only 37% of those polled supported nuclear energy (though 54% of Ontario residents did), while 53% of Canadians 'somewhat' or 'strongly' opposed it.[80] This data can be interpreted as several ways: as the product of thoughtful and well-informed analysis of Canada's nuclear experience, as a reflection of conclusions reached through limited understanding of the most accessible facts, or even as widespread misunderstanding within the Canadian public about the benefits, costs, and risks of nuclear technologies. As with Kearns and Lawson's analysis of the transfer of public housing stock in Glasgow, the nuclear industry faces a set of "die-hard opponents" and "professional and vested interests for whom the policy hasn't progressed as they imagined", which has grown with each international nuclear catastrophe, whether or not those events have much relevance for the Canadian experience.[81] Furthermore, if the primary purpose of the nuclear program was nation-building in

[78] Kearns and Lawson, "(De)constructing a policy 'failure': Housing stock transfer in Glasgow", p. 467.

[79] Notably, despite favourable geology in huge and highly stable rock formations, Canada has not yet developed a permanent repository for highly dangerous spent fuel bundles, which are currently kept in interim storage in cooling ponds and temporary dry fuel casks at the sites of Canadian nuclear power stations.

[80] Canadian Nuclear Association, *National Nuclear Attitude Survey*, p. 3, 10.

[81] Kearns and Lawson, "(De)constructing a policy 'failure': Housing stock transfer in Glasgow", p. 449.

the sense of technological capability, contemporary public assessments may be a lot less pertinent than the comparative capability of Canadian firms. CANDU may not have become a dominant reactor technology, but it is nonetheless notable that a state with the population and technical capabilities of Canada has had some success competing with states including the United States, Britain, France, and Japan.

In the end, Canada's experience with building nuclear reactors seems like a comparative success in terms of the development of a domestically-produced reactor technology that currently provides more than half of Ontario's electricity supply. Canada's nuclear industry employs about 21,000 people and has annual revenues of $5 billion.[82] Ontario's fleet of nuclear reactors has an electrical output of over 14,000 megawatts. While it wasn't a policy goal at the outset, it is also notable that Canada's nuclear reactors have led to 1.6 billion tonnes of avoided CO_2 emissions since 1972, if it is assumed that coal would otherwise have been burned.[83] Notably, these successes were not achieved within the cost estimates for the various projects involved. Canada succeeded in building a nuclear reactor industry for itself, but did so only at costs well beyond projections and with heavy government support. The success of CANDU as an export technology is more questionable, both in terms of the number of sales and the adverse impacts which have arguably accompanied them. Canada's record of medical isotope production is again a story of success in terms of serving the intended purpose for a long span, followed by failures in maintaining and expanding the capacity to do so. As a producer and exporter of nuclear materials, Canada can make the clearest claim to being successful, though this does not accord with the old aspiration for mastery of all aspects of civilian nuclear technology.

The final evaluation of Canada's nuclear legacy may become possible in the next couple of decades, as decisions are made about what to do with the commercial reactors in Ontario and New Brunswick. The decision to extend their lives or, more ambitiously, to construct new CANDU reactors would extend Canada's main nuclear story. Alternatively, it is quite possible that the federal government — along with the provinces of Ontario and New Brunswick — will opt to replace the CANDUs with foreign-designed reactors, or to phase out nuclear-generated electricity entirely.[84] Ordinarily, electricity supply planning might be expected to

[82] Coupland, *Clean Air and Dependable Electricity Generation - The Nuclear Option*, p. 2.
[83] Ibid., p. 12.
[84] See: Cadham, *The Canadian Nuclear Industry: Status and Prospects*.

involve a great deal of long-term certainty, given the decadal scales involved in the construction of new plants. Nuclear power, however, experiences a special volatility tied to fluctuating public sentiment in response to spectacular accidents like those at Three Mile Island in 1979, Chernobyl in 1986, and Fukushima in 2011.[85] Making a multi-decacal commitment to a new nuclear facility is a courageous choice for any government, given the probability that further such accidents may occur, abruptly extinguishing public support for such development.[86] This uncertainty is compounded by the possibility of major transformations in the technology and economics of energy generation generally. North America is experiencing a boom in unconventional hydrocarbons, as hydraulic fracturing yields vast amounts of 'tight' oil and gas. Improved energy efficiency, and the deployment of large quantities of new renewable energy and energy storage capacity may also undermine the economic case for new nuclear capacity. The early dreams of the world's nuclear proponents that fission would provide cheap, safe power have proven overly optimistic, and reactors have often proven more dangerous than their builders intended. Likewise, nuclear weapons capability has spread to an ever-larger set of states, many of whom face substantial security risks, both internally and externally. In this sense, the global experience with nuclear energy policy is similarly mixed, provides similarly ambiguous guidance for the future, and may offer generalizable lessons for policy evaluation scholarship.

[85] 70% of Canadians claim to have 'very closely' or 'somewhat closely' followed news reports about the Fukushima disaster, and 49% believe it 'very likely' or 'somewhat likely' that a similar event could occur in Canada. Canadian Nuclear Association, *National Nuclear Attitude Survey*, p. 26, 28.

[86] The experiences of Germany and Japan since the Fukushima crisis began are interesting in this regard, as policy-makers have sought to address widespread public hostility to the further use of nuclear energy while facing the challenge of replacing the energy output from nuclear plants in the short term, and possibly absorbing the wasted investment from shutting them down in the long term.

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