POLICY *Paper*

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# Canada needs policies to fill the gap in its nuclear fuel cycle

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## Introduction

November 28, 2024 was an important date in Canada's development of nuclear energy policy. On that day the Nuclear Waste Management Organization (NWMO) named the Wabigoon Lake Ojibway Nation (WLON) and the Township of Ignace, ON[1] as the host sites for Canada's deep geological repository. It marked a significant step, advancing the project to the regulatory decision-making process and towards closing the nuclear fuel cycle in Canada, which begins by mining uranium in Saskatchewan.

Having said that, between the two stages of mining and disposal, gaps remain in the uranium nuclear cycle that should be filled to add value to Canada's uranium and to position the country to meet its own, and the world's, increasing needs for nuclear fuel. The world's capacity is expected to grow from the current electrical capacity of 374,000 MWe (produced by 415 reactor units)[2] to 444,000 MWe by 2030 and 686,000 MWe by 2040[3]. Clearly, as the world transitions off fossil fuels and towards electrification , nuclear energy will play an increasing role in global energy supply.

This Policy Paper makes the case I set out in in a recent C.D. Howe Institute Intelligence Memo that called on the Canadian Government to clarify its policies regarding filling the enrichment and reprocessing gaps in the Canadian nuclear fuel cycle[4]. The issue is addressed here in five parts.

- First, is a brief description of the uranium fuel cycle;
- Second, a discussion of the capacity and the expected demand for uranium resources, specifically enriched-uranium fuel;
- Third, the role of reprocessing spent nuclear fuel, and the available global capacity is presented
- Fourth, a review of Canadian statues and policies and international obligations, regarding enrichment and reprocessing; and,
- Fifth, a call for the Government of Canada to establish clear policies and guidelines with respect to both enrichment and reprocessing, given that Canada is a leading exporter of uranium, a role that is likely to be further enhanced by the accelerated deployment of nuclear power called for by COP28'[5].

## Uranium Fuel Cyle

The uranium fuel cycle is illustrated in Figure 1. It starts by mining and milling, which is done in Canada using the high-grade deposits in Saskatchewan (Cigar Lake Mine, the McClean Lake Mil, McArthur River mine and Key Lake mill). It is then refined into a purified form of uranium trioxide ($UO_3$) domestically in Cameco's Blind River Refinery (world's largest commercial uranium refinery) in Ontario.

The conversion process involves converting $UO_3$ to either uranium dioxide ($UO_2$) or to uranium hexafluoride ($UF_6$), which is done at Cameco's Port Hope Conversion Facility, in Ontario. No enrichment is done in Canada, but $UF_6$ is exported[7] for enrichment in the U.S.A., Europe and Asia. Uranium dioxide is used in Canada to fuel CANDU reactors, which utilize natural (unenriched) uranium in the form of fuel pellets, assembled into fuel-rod bundles. CANDU fuel fabrication is done at Cameco's Port Hope facility and in BWXT Nuclear Energy Canada Inc. Toronto's and Peterborough's, ON, facilities.

After using the fuel in a nuclear reactor, the radioactive spent fuel is stored in water-filled fuel pools, for a few years until the fuel cools down, then in dry storage silos, and is eventually to be deposed of in a deep geological repository. Canada does not have reprocessing facilities. In reprocessing, plutonium and uranium are extracted from spent fuel and recycled into mixed oxides (MOX) fuel, with the remaining high-level waste isolated for disposal. Reprocessing not only produces new fuel material to power nuclear reactors, but also reduces the volume and radiotoxicity of the waste.

In summary, Canada's fuel cycle lacks the enrichment and reprocessing stages of the fuel cycle. The question is why these two stages are now relevant to Canada, given that they were not needed in the past. The reliance on CANDU reactors, which do not require enriched uranium, made it unnecessary to enrich uranium, and with uranium being plentiful in Canada there was no need to recycle the fuel. There may had been some none-proliferation considerations, though there were no legal or regulatory prohibitions as discussed below.

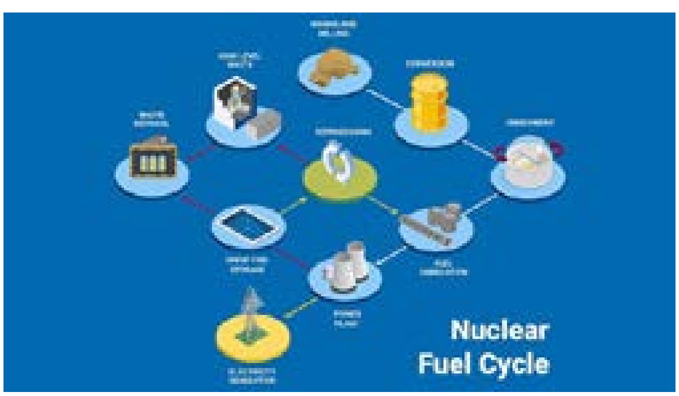



FIGURE 1: NUCLEAR FUEL CYCLE (SOURCE: INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA).

## Uranium Supply and Demand

There are various types of uranium. Natural uranium contains 0.72% of the fissile isotope U-235; the rest is mostly U-238. The heavy-water ($D_2O$) used in CANDU reactors is a weak neutron absorber, enabling operation with the low content of the fissionable U-235 in natural uranium. Reactors that use light water ($H_2O$), such as pressurized water reactors (PWRs) and boiling water reactors (BWRs), employ uranium enriched from 3 to < 5% in U-235; the so-called low-enriched uranium (LEU).

Emerging microreactors use high-assay low-enriched uranium (HALEU), enriched from 5 % close to the 20% enrichment limit allowed for civilian use of nuclear power. The higher enrichment prolongs the refuelling cycle, to the extent that a microreactor can be fuelled once for a thirty-year operation. This enables standalone operation with minimal operator intervention, suited for remote communities. There is also depleted uranium, the tailings of the enrichment process, which is mostly U-238, not a fissile isotope in common thermal-neutron reactors[8], but is converted to the fissile Pu-239 upon neutron absorption in these reactors and is fissionable in fast reactors. Finally, there is U-233, which does not naturally exist, but is produced by neutron absorption in thorium (Th-232). The latter is widely available in nature, mostly in monazite and bastnaesite, with worldwide thorium resources of about 6.2 million tonnes[9] (compared to about 8 million tonnes of reasonably recoverable uranium resources[10]).

The expected expansion in nuclear power will be matched by increase in the demand for uranium ores. The Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) provide a number of scenarios for the worldwide uranium supply and demand)[8]. Using the NEA/IAEA data, Figure 2 was produced to show the two highest and lowest expected uranium supply and demand scenarios. Figure 3 shows the uranium supply gap for high supply/low demand, low supply/high demand, and for the average of the two scenarios. Interestingly, visualcapitalist.com predicted a supply gap of 74,000 tonnes/year of tri-uranium octoxide ($U_3O_8$, a form of raw uranium), by 2040[11], which is equivalent to 62,751 tonnes of uranium/year. This value is close to that reported in Figure 3 for the deficit scenario (58,797 tonnes).

It should be noted that Canada's production is expected to represent by 2040 about 30% of the world's uranium supply[8], double the 15% contribution in 2022[12]. On the other hand, the market share of Canada's main competitor, Kazakhstan, is expected to decrease from the 43% level in 2022 to 14 -18% by 2024. Therefore, Canada is posed to become the largest uranium producer, with the added competitive advantage of having a lower production cost because uranium concentrations in Saskatchewan are up to 100 times higher than the world's average high-grade deposits[12].

Regardless of the scenario, Figures 2 and 3 show that the demand for uranium is likely to exceed the supply, if the expected expansion in nuclear power materializes. According to the World Nuclear Organization (WNA), current uranium resources (reasonably assured plus inferred) are about 6.1 million tonnes[13].

Therefore, uranium supply can meet the demand for about 56 to 96 years, using the 2040 demand levels. There is also a room to increase uranium resources from the current assured 6.1 million tonnes to 8 million tonne of reasonably recoverable uranium resources[8]. However, the availability of natural uranium resources is not the only factor for ensuring adequate supply of nuclear fuel as most operating reactors and many emerging advanced reactors rely on enriched uranium.

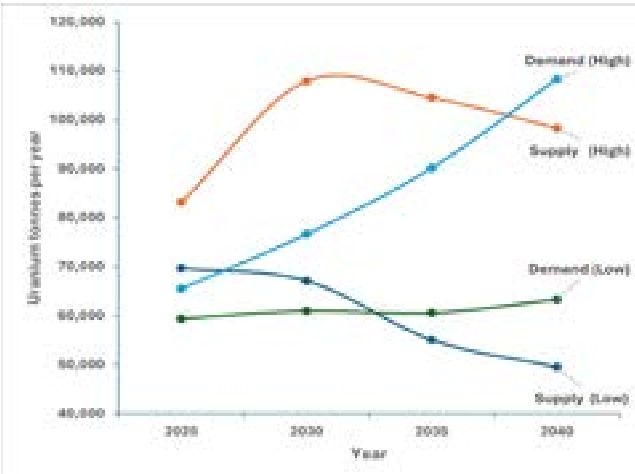



FIGURE 2: EXPECTED URANIUM SUPPLY (PRODUCTION) AND DEMAND (CONSUMPTION) IN HIGH AND LOW SCENARIOS (SUPPLY INCLUDES PLANNED AND PROSPECTIVE EXPLORATION AT A COST UP TO US$130/KG URANIUM); DATA FROM A RECENT IAEA/NEA REPORT[8].

## Uranium Enrichment Capacity

As Figure 4 demonstrates, most advanced reactors will employ enriched uranium, some at levels higher than the common LEU (≤ 5% enrichment). As the Figure shows, a number of reactor designs rely on HALEU (5 to < 20% enrichment), with low-power reactors (microreactors) using enrichment levels close to the HALEU upper limit of 20%. It is evident that reliance on enriched uranium will continue. Even in Canada, where CANDU reactors dominated, Ontario Power Generation and SaskPower are to acquire BWRX-300 reactors (3.8 / 4.95% enrichment), Ontario Power Generation and the Canadian Nuclear Laboratories are demonstrating the MMR-5 technology (9.9 to 19.75%), the Saskatchewan Research Council and Bruce Power are collaborating on the development of eVinci™ (19.75%), and Cameco is involved with Xe-100 (15.5%); where the numbers in parentheses are the enrichment level(s) to be used in these reactors.

As Canada is adopting non-CANDU technology, and without having any enrichment facilities, Canadian operators will have to import enriched uranium and compete with other jurisdictions embracing similar reactor technologies. In 2021[14], Russia's Rosatom had 44% of the world uranium enrichment capacity, with Europe's (France's Orano and Britain-Germany-Netherlands' Urenco) 34%, China's CNNC at 15%, the USA's Urenco 7.5%, and the rest of the capacity is provided by other countries (Argentina, Brazil, India, Pakistan, and Iran). By 2030, WNA expects the world's enrichment capacity to increase by about 14%, with Orano providing 36% of the world's capacity, 39% by Rosatom and 24% by CNNC. In the U.S.A., Urenco plans to increase the capacity of its Eunice plant by 15%[15]. "There are no current commercial suppliers of HALEU in the West"[16]. Russia's TENEX is the only commercial supplier of HALEU worldwide[17]. However, the US Congress allocated, in its 2013 Inflation Reduction Act, US$700 million for the development of a commercial supply chain for HALEU[18].

It is obvious that advanced reactors employing HALEU fuel will either rely on one company in a country currently under economic sanctions or await the uncertain future of developing HALEU technology in the West. The production of HALEU is demanding, as it takes about 42 Separation Work Units (SWU: effort required to separate U-235 and U-238) to produce 1 kg of 19.75% HALEU from about 40 kg of natural uranium, while only 5 SWU is needed to produce 1 kg of 3.5% enriched uranium from about 7 kg of natural uranium[19]. The U.S. is currently down-blending some if its highly enriched weapon-grade uranium[20] to meet its domestic demand for HALEU, but it is not clear whether some of that fuel will be exported. In summary, currently and in the near future most of the global production of LEU and HALEU will be by Russia and China, not a very comfortable situation for many Western countries.

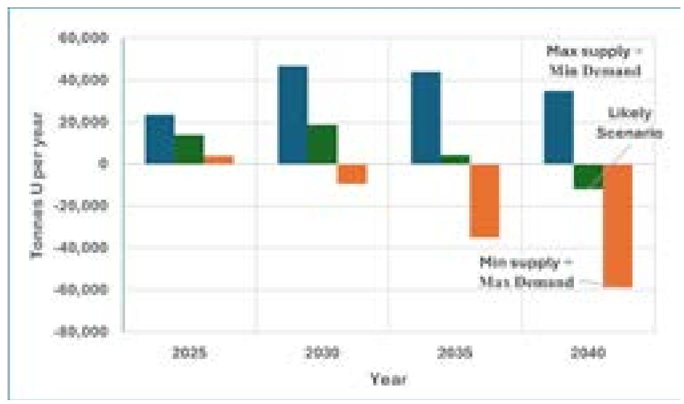



FIGURE 3: EXPECTED DEFICIT/SURPLUS IN NATURAL URANIUM (SUPPLY INCLUDES PLANNED AND PROSPECTIVE EXPLORATIONS AT A COST UP TO $US130/KG URANIUM); DATA FROM A RECENT IAEA/NEA REPORT[8].

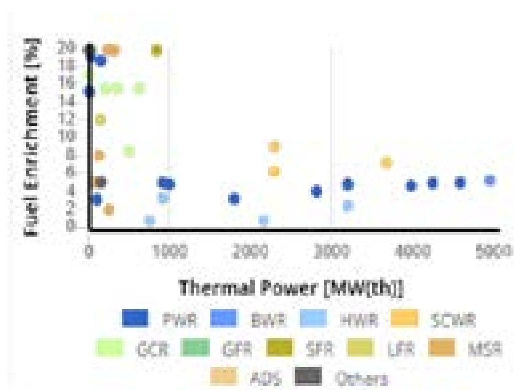



FIGURE 4: ENRICHMENT LEVELS FOR VARIOUS ADVANCED REACTOR TYPES[21]: PWR: PRESSURIZED LIGHT-WATER REACTOR, BWR: BOILING LIGHT-WATER REACTOR, HWR: HEAVY-WATER REACTOR, SCWR: SUPERCRITICAL-WATER REACTOR, GCR: GAS- COOLED REACTOR, GFR: GAS-COOLED FAST REACTOR, SFR: SODIUM-COOLED FAST REACTOR, LFR :LEAD-COOLED FAST REACTOR, MSR: MOLTEN-SALT REACTOR, ADS: ACCELERATOR DRIVEN SYSTEM.

## Fuel Recycling/Reprocessing

Nuclear fuel consists of mostly of U-238, some of which is converted to fissile Pu-239 and Pu-241, and not all the fuel's U-235 is consumed in a reactor. Therefore, discharged spent fuel still contains fissile isotopes that can be recovered via reprocessing and recycled for reuse as nuclear fuel, "saving up to 30% of the natural uranium otherwise required"[22]. Reprocessing also leads to the separation of minor actinides[23] that can be burned in fast reactors. The current global fuel reprocessing capacity is shown in Table 1, which includes only thermal reactors, as fast reactors are designed to burn reprocessed MOX fuel. It should be noted that the heavy-water fuel of India's reactors listed in the Table is similar to that of CANDU's fuel.

*TABLE 1 WORLD'S COMMERCIAL SPENT FUEL REPROCESSING CAPACITY IN TONNES OF*

| SPENT FUEL FROM: | | | | | |
|---|---|---|---|---|---|
| WATER-COOLED REACTORS | | | GAS-COOLED REACTORS | HEAVY-WATER REACTORS | TOTAL |
| FRANCE, LA HAGUE | RUSSIA OZERSK (MAYAK) | JAPAN (ROKKASHO) TOTAL | UK, SELLAFIELD (MAGNOX) | INDIA, 4 PLANTS | |
| 1,700 | 400 | * | 1,500 | 260 | 3,860 |

** Production is planned to start in 2025, reaching 280 tonnes in 2028[27].*

The reprocessed fuel can fill the gap in natural-uranium supply, if the demand exceeds the supply in the scenario shown in Figure 3, particularly by 2040. However, reprocessing of spent nuclear fuel may not be essential until 2040. Nevertheless, reprocessing reduces the mass and radiotoxicity of nuclear waste materials[24]. It is estimated that reprocessing spent nuclear fuel "from thermal reactors reduces radioactive waste for disposal by almost 20 times, since only fission products having a mass typically not exceeding 5–6% of such fuel require to be disposed"[25]. As David Jackson indicated in 2003 if "there was a decision to reprocess CANDU fuel….there would be no purely technical obstacle to domestic reprocessing"[22].

## Canadian and International Statues

The uranium supply data shows that Canada will become the world's largest producer of uranium. If the current situation remains unchanged, Canada will continue to export uranium with little value added to its raw mineral. The increased reliance on enriched uranium offers an opportunity for Canada to add value to this precious resource by enriching it, while securing its own domestic needs as it acquires advanced nuclear reactors. Although, as indicated above, fuel reprocessing may not be necessary to meet the emerging demand for nuclear fuel, at least in the near future, it can play an important role in reducing the size and radiotoxicity of Canada's spent nuclear fuel[29]. The question therefore is: are their any national policies/laws or international obligations/treaties that stop Canada from having its domestic enrichment and/or reprocessing operations?

As far as enrichment is concerned, there are no explicit official domestic prohibitions on enriching uranium. In fact, in 1973, the then Canada's Minister of Energy, Mines and Resources, Donald S. Macdonald, issued a statement on the establishment of uranium enrichment facilities in Canada. It concluded that "[a]n enrichment project could not be considered an essential national project in Canada," but it would be "a secondary industry in which a raw material of either domestic or foreign origin would be further processed."[29]

The possibility of enriching uranium in Canada was revisited in 2009, in a study by the Centre for International Governance Innovation. This study indicated that "enrichment in Canada is likely to be more profitable than exporting natural uranium and buying back enriched uranium. We expect that a significant domestic market for enriched uranium will arise in the years following 2012 when new reactors using enriched fuel are expected to be built in Canada."[30] The time is approaching soon for Canada having reactors that use enriched uranium.

Internationally, Canada is a party to the Treaty on the Non-Proliferation of Nuclear Weapons[31], and had signed in 2000 an agreement with the IAEA for the application of related safeguards[32]. This is the treaty upon which Canada's policy on nuclear non-proliferation and disarmament is based, which includes a "limitation on enrichment of Canadian nuclear material to less than 20%[33]. In summary, there appear to be no internal legal hurdles and no international constraints that prevent Canada from enriching uranium. An obvious concern for many is that reprocessing of spent fuel produces plutonium, a material that can be used in a nuclear weapon. However, Canada as a partner of the Non-Proliferation Treaty is subject to inspection and monitoring by the IAEA, to ensure that the treaty's intention of not diverting nuclear materials to weapons is followed. In fact, "[c]o-operation between the IAEA and a State is necessary for the successful implementation of safeguards in any context."[34] In addition, as a nuclear-industry recycling/reprocessing task team indicated, "there appears to be no policy inhibitors to prevent the reprocessing of used nuclear fuel for peaceful purposes in Canada".[35]

The same study also contended that "Canada has an extensive legislative and regulatory framework that appears to address" six guiding principles identified by the team." These are: (i) ensuring peaceful uses of reprocessed fuel, (ii) meeting Canada's international obligations, (iii) limiting risks to the health and safety of the public and the environment, (iv) long-term management of generated radioactive wastes, (v) limiting risks related to the transportation of reprocessed fuel, and (vi) controlling nuclear substances import/export of equipment and information via nuclear cooperation agreements and additional protocols to Canada's safeguards agreement with the IAEA.

There appears to be an impression that "Canada's policy on reprocessing at some point changed to accord with the US policy declared by President Carter in 1977"[23], and that "Canadian Policy regarding non-proliferation assumes no enrichment or reprocessing in Canada"[36]. "It is worth pointing out that President Carter's policy was expressed in the amendment to the U.S.' Nuclear Non-Proliferation Act of 1978. "The Amendment barred U.S. economic and military assistance to any country that imported or exported spent nuclear fuel reprocessing or uranium enrichment equipment, materials, or technology but failed to comply with International Atomic Energy Agency (IAEA) full-scope safeguards".[37] But as indicated above, Canada is a partner to the non-proliferation treaty. Moreover, Canada's Policy for Radioactive Waste Management and Decommissioning states that "Reprocessing in Canada would require consideration of all relevant factors by the federal government prior to its deployment, including ensuring the health, safety and security of people in Canada, and compliance with non-proliferation safeguards and international treaties"[38]. This indicates that Canada is not prohibiting reprocessing.

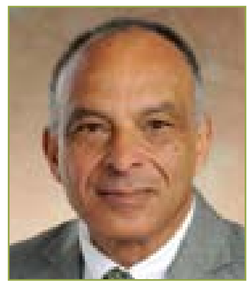
## Conclusion

There are no apparent legal national inhibitions and no international restrictions on Canada developing uranium-enrichment and spent-fuel reprocessing industries. Having such capacities will add value to Canada's large uranium exports, secure its own supply of enriched uranium as it acquires advanced reactors, and reduce the size and radiotoxicity of the accumulating spent fuel inventory. Reprocessing will also be needed to operate at least in one of the reactors being developed in Canada[39].

As a major producer of uranium, Canada is in a strong position to demand the acquisition or access to enriched and reprocessed fuel and/or associated technologies from countries that possess such fuel and technology. The absence of clear policies on enrichment and reprocessing can be a hindrance to the domestic development of related technologies and may be understood as being a silent prohibition. Therefore, the Government of Canada should establish clear policies and regulations on enrichment and reprocessing to guide the nuclear industry in acquiring suitable reactor technologies with secured fuel supply. Beyond the opportunity for Canada to engage in the completion of the nuclear fuel cycle, one can argue that as a major uranium producer, Canada has an obligation to join other Western countries in developing enrichment\reprocessing industries that can compete with Russia and China to support the rapidly emerging advanced reactors.

The European model, in which governments partially own enrichment companies, such as Urenco and Orano, is a good one to follow, as it enables governments to meet their international treaty obligations. The Atlantic Council's Eurasia Center pointed out in April 2023 that with a "potential United States (US) and/or European Union (EU) ban on uranium civilian reactor fuel exports from Russia…, Kazakhstan could double its share of the European market if it builds its own conversion and enrichment facilities"[40]. The banning has already occurred. On May 13, 2024, U.S. President Biden signed the Prohibiting Russian Uranium Imports Act, ruling out "the import of Russian uranium products into the United States as of August 12, 2024"[41]. Moreover, Russia responded by placing its own ban on exporting uranium to the U.S.[42] There is also the uncertainty caused by the Nigerien authorities taking over control of the 63.4% Orano-owned uranium mine in Arlit , Niger (a leading producers of uranium)[43]. The time is right for Canada to consider having its own uranium enrichment industry. Canada has its own conversion (to $UF_6$) facilities that serve as a springboard to the development of enrichment facilities.

Canada is not unfamiliar with reprocessing radioactive materials, as it had been used to extract nuclear isotopes from irradiated targets. Reiterating David Jackson's conclusion in 2003, there are "no purely technical obstacle[s] to domestic reprocessing"[23] . It is about time to reexamine the feasibility of establishing a reprocessing industry in Canada.



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