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# Opportunities for Canadian Small Modular Reactor Policy

**Major Jason Dalziel**

## JCSP 49

## Exercise Solo Flight

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## PCEMI n° 49

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# OPPORTUNITIES FOR CANADIAN SMALL MODULAR REACTOR POLICY

## INTRODUCTION

The ongoing war in Ukraine has propelled energy security to the top of the agenda of many nations. The war has challenged global assumptions about the reliability of the supply of fossil fuels, and when coupled with commitments to reduce greenhouse gas (GHG) emissions, it has sparked a renewed interest in clean energy to fill a growing gap in global energy demand. While renewables will make up some of the solution, nuclear is increasingly seen as a viable clean energy option. Canada, owing to its strong history of producing and exporting nuclear power, has invested heavily in the development of small modular reactors (SMRs) through the SMR Action Plan, and now is poised to develop this technology domestically as well as contribute to global exports. This commitment will serve to continue its position of global leadership in the supply of nuclear power domestically and abroad, however, in doing so Canada should also consider how such investments might be leveraged to strengthen its position in defence, and security. A subcategory of SMRs, Micro Modular Reactors (MMRs), if developed adequately, could serve to increase energy security within Canada's remote regions, contribute to GHG reductions, and permit future exploration of decarbonized security operations.

These investments will also challenge Canada's position as a strong supporter of the global anti-nuclear proliferation regime. The SMRs' lack regulatory coherence at present and their propagation will pose proliferation risks to the global community. The interwovenness of the Canada-US industry, and the economics of SMRs imply that Canada will have difficulty maintaining a strong international nuclear export presence without the United States (US). Deft diplomacy and policy navigation will be necessary to maintain Canada's position as a strong voice in the nuclear regulatory community as the US's diplomatic dominance is challenged by Chinese and Russian expansion. This expansion may not only amount to missed economic opportunities for Canada, but also may challenge the strength of the non-proliferation regime.

Canada has an opportunity to enhance its influence on the world stage by leveraging its history of safe use and exportation of nuclear power through the adoption of SMRs and MMRs, which not only offer significant economic and environmental benefits but also have immense potential for defense and security purposes. This essay will discuss the advantages and challenges of SMRs, their utility for defense purposes, and how they fit into Canadian domestic and foreign policies.

## NUCLEAR POWER IN CANADA

Canada has a long history of developing, using, and exporting safe nuclear power, it was the 2nd nation to produce power and remains in a position of technological leadership as a 'tier 1' nuclear nation with a robust domestic supply chain, strong regulatory framework, and mature institutions[1]. The most notable achievement is the

[1] Natural Resources Government of Canada, 'Canada's National Statement on Nuclear Energy', statements, 26 October 2022, https://www.canada.ca/en/natural-resources-canada/news/2022/10/canadas-national-

design of the Canada Deuterium Uranium (CANDU) reactor, of which there are 31 currently operating worldwide. The reactor design uses a 'defence-in-depth' safety philosophy which resulted in strong safety performance since the first demonstration reactor was commissioned in 1962[2]. The CANDU fuel design uses unenriched uranium the potential weapon proliferation risks are minimized, which has increased the acceptability of widespread export of the design even to countries with which Canada had limited security sharing agreements such as: China, India, South Korea, Argentina, Pakistan, and Romania[3]. The export of the CANDU has led to stronger ties with partner nations as research, development, and engineering costs to maintain and make incremental improvements to the reactor have continued since 1984[4].

While nuclear power fell out of political favor in recent years due to optimism surrounding renewable energies (e.g. wind, solar, tidal), dependence on weather for supply and challenges with energy storage[5] have resulted in a reconsideration of the importance of nuclear as an alternative to other persistent generating sources like fossil fuels. Some 15% of the electricity in Canada is currently produced by nuclear power, and over half of electricity in Ontario[6]. Many CANDU reactors in Canada have already undergone midlife refurbishment and will need to be replaced in the coming decades[7], which has in turn prompted further study of newer designs that could replace the output of the venerable CANDU and reinvigorate the Canadian nuclear industry.

## SMRS: ADVANTAGES AND CHALLENGES

SMRs are generally defined as fission reactors that produce less than 300 MWe and are composed of several factory assembled submodules which when combined, allow for the construction of a power plant by adding modules to a single site incrementally to achieve the desired power output[8] . When construction is done in this manner, capital costs and decisions for plant construction can be spread over time to match demand, as opposed to investing in a larger plant upfront to provide the power output needs for its lifecycle. While these SMRs are not yet in commercial operation, they are generally expected to be safer, simpler to operate, have lower upfront capital costs, occupy less space, and require less construction time when compared to constructing new larger

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statement-on-nuclear-energy--the-honourable-jonathan-wilkinson-minister-of-natural-resources--the-international-atomic-energy-agen.html.

[2] H. Y. Tammemagi, David Jackson, and H. Y. Tammemagi, *Half-Lives: The Canadian Guide to Nuclear Technology* (Oxford University Press, 2009).

[3] Tammemagi, Jackson, and Tammemagi.

[4] CANDU Owners Group, 'About', CANDU, accessed 28 March 2023, http://www.candu.org/Pages/About.aspx.

[5] 'Electricity - Fuels & Technologies', IEA, accessed 29 March 2023, https://www.iea.org/fuels-and-technologies/electricity.

[6] Canada Energy Regulator Government of Canada, 'CER – Provincial and Territorial Energy Profiles – Canada', 3 March 2023, https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-canada.html.

[7] Canadian Nuclear Association, 'Current Fleet Refurbishment', 2 March 2020, https://cna.ca/research-and-advocacy/refurbishment/.

[8] *Handbook of Small Modular Nuclear Reactors*, Second edition, Woodhead Publishing Series in Energy (Oxford: Woodhead Publishing, an imprint of Elsevier, 2021).

plants[9]. In addition to producing clean power, SMRs have the added benefit of efficiently producing steam for either heating or industrial applications and are also ideal for desalination of water[10]. Figure 1 shows the proposed layout of the General Electric Hitachi BWRX-300, planned to be operational in 2028, it will be North America's first SMR[11].

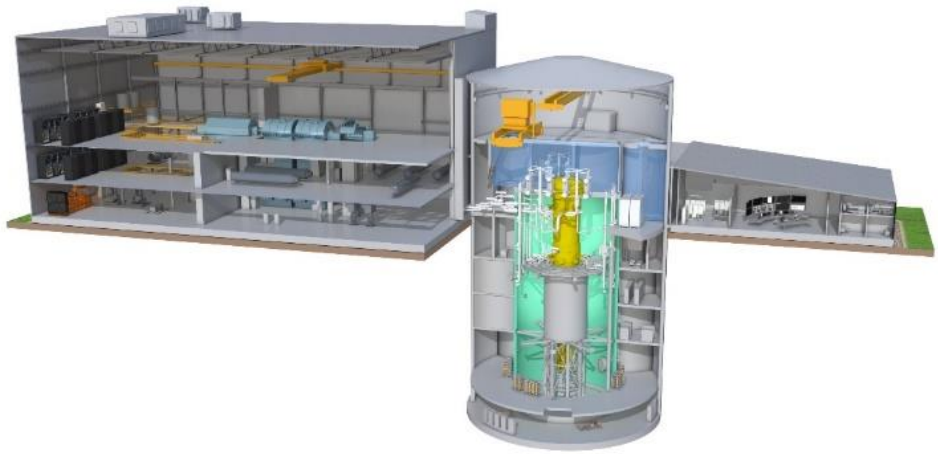

**Figure 1: Proposed layout of the Hitachi BWRX-300.**
*Source: GE Power 'BWRX-300'.*

SMRs also have some drawbacks when compared to traditional nuclear reactors. First, economic estimates are mixed with pessimistic conclusions that they are only considered to be cost competitive to larger scale reactors already in operation which have no research and development costs[12]. Second, there are concerns over greater nuclear waste production as some designs produce more waste per MWe of power, and "designs that optimize one metric, say waste volume, might make other challenges, such as the risk of severe accidents, more acute"[13] making it difficult to generalize claims that SMRs are safer and decrease nuclear waste production. Finally, SMRs raise concerns for nuclear proliferation, as the number of reactors increases so does the demand on the security apparatus to keep track of nuclear materials, this concern will be specifically addressed later in this paper.

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[9] Raffaella Testoni, Andrea Bersano, and Stefano Segantin, 'Review of Nuclear Microreactors: Status, Potentialities and Challenges', *Progress in Nuclear Energy* 138 (1 August 2021): 103822, https://doi.org/10.1016/j.pnucene.2021.103822; 'Small Modular Reactor Feasibility Report | Ontario.Ca', accessed 23 March 2023, http://www.ontario.ca/page/small-modular-reactor-feasibility-report.

[10] Giorgio Locatelli, Chris Bingham, and Mauro Mancini, 'Small Modular Reactors: A Comprehensive Overview of Their Economics and Strategic Aspects', *Progress in Nuclear Energy* 73 (1 May 2014): 75–85, https://doi.org/10.1016/j.pnucene.2014.01.010.

[11] GE Power, 'BWRX-300', accessed 25 April 2023, https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/bwrx-300.

[12] Stephen Thomas and M. V. Ramana, 'A Hopeless Pursuit? National Efforts to Promote Small Modular Nuclear Reactors and Revive Nuclear Power', *WIREs Energy and Environment* 11, no. 4 (2022): e429, https://doi.org/10.1002/wene.429.

[13] M. V. Ramana, 'Small Modular and Advanced Nuclear Reactors: A Reality Check', *IEEE Access* 9 (2021): 42095, https://doi.org/10.1109/ACCESS.2021.3064948.

## MICRO MODULAR REACTORS AND THE UTILITY FOR DEFENCE PURPOSES

A subcategory of SMRs are micro modular reactors (MMR) (or microreactors), which are those which produce less than 10MWe[14]. These reactors are different than SMRs in that they are faster to set up, sometimes taking only a few days, are small enough to be deployed or redeployed by a variety of methods (air transport, sea, rail or road), can function both on and off grid, and have relatively low sustainment requirements in terms of operation and refueling[15]. Generally, MMRs are not as economical to operate as SMRs but are being considered for off-grid applications where the logistics of moving fuel (generally diesel) are challenging or expensive. These include remote mining sites and military installations, microgrids to power key infrastructure during a disaster, and isolated communities such as in Canada's north – particularly where renewables are not viable due to space or weather[16]. Figure 2 shows the size and transportability of the Ultra Safe MMR which is planned to be operational at Chalk River Nuclear Labs in 2026[17].

**Figure 2: The Ultra Safe MMR. The reactor can be broken down into modules and transported in standard shipping containers.**

*Source: NucNet 'Microreactors / Ultra Safe Seeks Funding For Two Demonstration Plants In US by 2026'.*

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[14] *Handbook of Small Modular Nuclear Reactors*.

[15] Kenneth S Allen, Samuel K Hartford, and Gregory J Merkel, 'Feasibility Study of a Micro Modular Reactor for Military Ground Applications', *Journal of Defense Management* 08, no. 01 (2018), https://doi.org/10.4172/2167-0374.1000172; Testoni, Bersano, and Segantin, 'Review of Nuclear Microreactors'; G. Black et al., 'Prospects for Nuclear Microreactors: A Review of the Technology, Economics, and Regulatory Considerations', *Nuclear Technology* 209, no. sup1 (31 January 2023): S1–20, https://doi.org/10.1080/00295450.2022.2118626.

[16] Black et al., 'Prospects for Nuclear Microreactors'.

[17] David Dalton, 'Microreactors / Ultra Safe Seeks Funding For Two Demonstration Plants In US by 2026', NucNet, The Independent Global Nuclear News Agency, 2 October 2020, https://www.nucnet.org/news/ultra-safe-seeks-funding-for-two-demonstration-plants-in-us-by-2026-10-1-2020.

MMRs are proposed for defence purposes because it is expected that future operating environments may need to be self-sufficient for power generation, as re-supply of fuel may be made more difficult. Future operations will likely need to content with a contested logistics environment which is defined as “an environment in which the armed forces engage in conflict with an adversary that presents challenges in all domains and directly targets logistics operations, facilities, and activities”[18]. Having a source of power can also facilitate the production of fuels such as hydrogen which may power vehicles and smaller generators in the future. “Hydrogen can be generated and used at the tactical edge of the battlefield, whereas petroleum fuels have to be extracted, refined, stored, and transported long distance”[19] making it advantageous in situations where the supply chain is cut-off, or a host nation is unable or unwilling to provide fuel for an expeditionary operation. The ability to generate fuel has resulted in increased interest in robust power generation technologies capable of sustaining the Army’s future’s capabilities in all-weather scenarios[20].

Another reason why Canada might pursue MMRs is to improve its domestic response capabilities to natural disasters. While a transportable MMR cannot generate sufficient power for large cities in their entirety, they can provide enough energy for key infrastructure to continue to operate on a microgrid for extended periods. During a disaster, MMRs could be used to power hospitals, airports, water treatment plants, military installations, and other key infrastructure within a matter of days[21]. Importantly, this can be done even in remote communities, such as in Canada’s north.

The US Army has begun to study Mobile Nuclear Power Plants (MNPP) for ground operations and have found that the technological readiness is rapidly maturing without initiating a Department of Defence led research effort[22]. The US Army proposes to allow MMR technology to mature, with Army stakeholder input, under the control of the Department of Energy who has more expertise on the file. A similar construct would be reasonable in Canada as the Department of National Defence (DND), at present, has very limited expertise in nuclear power generation but could draw on national expertise in collaboration with Natural Resources Canada (NRC) and its agencies who already have very robust programs to guide the certification and licensing of SMRs and MMRs in Canada.

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[18] Michael Hugos Hazen Edward Salo, Ryan Kuhns, Ben, ‘Logistics Determine Your Destiny: What Russia’s Invasion Is (Re)Teaching Us about Contested Logistics’, Modern War Institute, 9 August 2022, para. 1, https://mwi.usma.edu/logistics-determine-your-destiny-what-russias-invasion-is-reteaching-us-about-contested-logistics/.

[19] Walker Mills Limpaecher Erik, ‘The Promise of Hydrogen: An Alternative Fuel at the Intersection of Climate Policy and Lethality’, Modern War Institute, 27 December 2021, para. 2, https://mwi.usma.edu/the-promise-of-hydrogen-an-alternative-fuel-at-the-intersection-of-climate-policy-and-lethality/.

[20] Limpaecher, ‘The Promise of Hydrogen’.

[21] Testoni, Bersano, and Segantin, ‘Review of Nuclear Microreactors’.

[22] Juan A Vitali et al., ‘Mobile Nuclear Power Plants for Ground Operations’ (Washington DC: Office of the Deputy Chief of Staff (G4) for Logistics (Army), 2018).

## DOMESTIC POLICY FOR SMRS

Canada is progressing towards building SMRs and in 2020 released a formal Action Plan on SMRs which commits to "development, demonstration, and deployment of SMRs for multiple applications at home and abroad… [to] "unlock a range of benefits: economic, geopolitical, social, and environmental"[23]. Bratt argues that "Canada is pursuing SMRs to reduce its greenhouse gas (GHG) emissions in order to meet its international and domestic climate change commitments, but also to capitalize on existing nuclear capabilities"[24]. He notes that SMR investments and partnering demonstrate an unusual case of intergovernmental cooperation between federal and provincial governments in Canada in the highly disputed area of energy policy, due to the importance of the technology to Canada's nuclear sector amid rising global interest. Some of the evidence for this assertion are found within the memorandum of understanding (MOU) signed by the provinces of Ontario, Saskatchewan, New Brunswick, and Alberta which commits to cooperation between the provinces and with the Federal Government on five key areas: "technology readiness, regulatory frameworks, economics and financing, nuclear waste management, and public and indigenous engagement"[25]. The broad consensus between Provincial and Federal Governments implies that the importance of nuclear power to Canada's economy spans beyond Ontario who is the most heavily vested and nuclear power is important to national the interest.

Beyond replacing existing CANDU reactors, a second part of Canada's interest in SMRs relates to MMRs powering remote off-grid locations. These include small, isolated communities, such as in Canada's north, as well as industrial applications primarily for resource extraction in remote areas[26]. Many remote communities, mines, as well as oil and gas extraction require large amounts of energy, and the current primary method of powering these operations is through fossil-fuel burning generators.

Canada's SMR policy is not without controversy and several scholars have pointed out that they are expensive when compared to other sources of energy and criticize government estimates as overly optimistic[27]. Part of this economic criticism is based in the ability for the nuclear industry to achieve economies of scale, since SMRs are constructed and maintained in a fixed facility, a certain throughput of manufacturing and maintenance work must be achieved for businesses to be economically viable[28]. In Canada the consumers of such services are governments and their agencies who operate power plants (e.g. Bruce Power in Ontario), so this criticism is generally one of government commitment, and minimizes government analysis on the size of the export

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[23] Natural Resources Government of Canada, 'Canada's SMR Action Plan Progress Update', n.d., 39.
[24] Duane Bratt, 'SMRs in Canada: Federal-Provincial Cooperation in Pursuing Net-Zero Emissions', *Canadian Foreign Policy Journal* 28, no. 3 (2 September 2022): 306, https://doi.org/10.1080/11926422.2022.2116063.
[25] Ontario Ministry of Energy, 'A Strategic Plan for the Deployment of Small Modular Reactors', accessed 23 March 2023, http://www.ontario.ca/page/strategic-plan-deployment-small-modular-reactors.
[26] Black et al., 'Prospects for Nuclear Microreactors'.
[27] Ramana, 'Small Modular and Advanced Nuclear Reactors'; Thomas and Ramana, 'A Hopeless Pursuit?'
[28] Thomas and Ramana, 'A Hopeless Pursuit?'

market is for SMRs[29]. The Organization for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) gives optimistic estimates that "the global SMR market could reach 21 gigawatts by 2035 … and 375 gigawatts by 2050"[30] which could make up a significant portion of the 1136 gigawatts it predicts are needed for the world to meet net zero targets by 2050[31]. The NEA also recognizes the conservative estimates for global nuclear power contributions, and the contrast in these estimates are shown in figure 3.

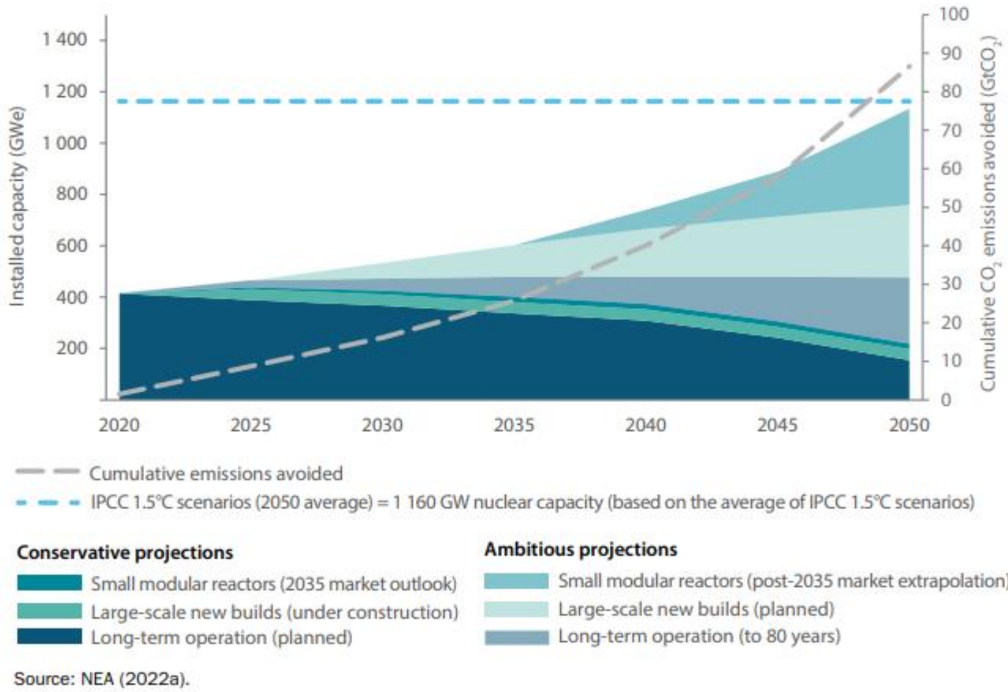


**Figure 3: Potential of Nuclear Contributions to Net Zero Power Generation.**
*Source: NEA 'The NEA Small Modular Reactor Dashboard', 13*[32]

If SMR interested nations were to reach suitable agreements on diving the industrial benefits of SMRs than there is potential to make nuclear a more cost-effective option[33]. In budget 2023, the Federal Government introduced new subsidies for clean energy and manufacturing technology, which will provide substantial incentives for firms to continue to invest in research, development, new machinery, and equipment of nuclear

[29] Sarah Froese, Nadja C. Kunz, and M. V. Ramana, 'Too Small to Be Viable? The Potential Market for Small Modular Reactors in Mining and Remote Communities in Canada', *Energy Policy* 144 (1 September 2020): 111587, https://doi.org/10.1016/j.enpol.2020.111587; S Allen, K Hartford, and J Merkel, 'Feasibility Study of a Micro Modular Reactor for Military Ground Applications'.
[30] 'The NEA Small Modular Reactor Dashboard', Nuclear Energy Agency (NEA), 13, accessed 19 April 2023, https://www.oecd-nea.org/jcms/pl_78743/the-nea-small-modular-reactor-dashboard?details=true.
[31] 'The NEA Small Modular Reactor Dashboard'.
[32] 'The NEA Small Modular Reactor Dashboard', 13.
[33] Armond Cohen and Kenneth Luongo; Ted Nordhaus; Michael Golay; Wade Allison; Allison Macfarlane, 'Going Nuclear on Climate Change', *Foreign Affairs*, 3 November 2021, https://www.foreignaffairs.com/articles/world/2021-11-03/going-nuclear-climate-change.

energy[34]. Beyond these incentives, Canada must also consider how to reach the threshold of exports needed to have a viable industry if it wants to maintain economies of scale for its nuclear industry –to lower the cost of deployment for these reactors to achieve more market penetration and ultimately meet the optimistic estimates produced by the OECD.

While Canada's SMR Action Plan is quite comprehensive, covering several economic and environmental advantages to pursuing the technology, it does not have a defence nexus, and DND was not part of the initial stakeholder engagements within the federal government when the plan was starting to take form in 2018[35]. This lack of collaboration with DND could manifest in missed opportunities, particularly as it pertains to emergency preparedness and response (in which the CAF's role as been increasing in recent years through Operation LENTUS) as well as in technological expertise in nuclear technology for future procurement, such as nuclear propulsion for naval vessels. With Canada's SMR Action Plan, it committed to maintaining its status as a nuclear nation, however, a reengagement is needed to exploit this in status in security, and defence.

## DEFENCE POLICY FOR SMRS

*Strong, Secured, Engaged: Canada's Defence Policy* (SSE), commits to examining alternative energy sources to reduce GHG emissions for operations in initiative 102, but does not recognize nuclear energy specifically[36]. However, there has been significant advancement in the SMR licensing process since SSE was released, and the investments already taking place within Canada might allow the DND to leverage these investments for filling its own requirements.

Defence Energy and Environment Strategy (DEES) commits to both reducing the GHG emissions from infrastructure as well as operations. The strategy commits the DND to reduce its emissions to 60% of 2005 levels by 2030 and to 20% of 2005 levels by 2050 with an aspiration for net-zero[37]. At present, DND may be able to meet the 2030 target, while it has reduced emissions by 37% since the program was introduced in 2017[38], however, the rate of reduction of emissions has been minimal since 2011 and will need significant effort to meet ultimate near net-zero targets in 2050. Figure 5 shows departmental GHG emissions by year from 2010 to present, demonstrating the lack of advancement towards DEES targets.

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[34] Department of Finance Government of Canada, 'Chapter 3: A Made-In-Canada Plan: Affordable Energy, Good Jobs, and a Growing Clean Economy | Budget 2023', 28 March 2023, https://www.budget.canada.ca/2023/report-rapport/chap3-en.html#a6.

[35] Natural Resources Government of Canada, 'Canada's Small Modular Reactor (SMR) Action Plan' (Natural Resources Canada), accessed 1 April 2023, https://smractionplan.ca/.

[36] National Defence Government of Canada, 'Strong, Secure, Engaged: Canada's Defence Policy', navigation page - audience page, 31 May 2019, https://www.canada.ca/en/department-national-defence/corporate/reports-publications/canada-defence-policy.html.

[37] National Defence Government of Canada, 'Defence Energy and Environment Strategy', 6 October 2017, https://www.canada.ca/en/department-national-defence/corporate/reports-publications/dees.html.

[38] National Defence Government of Canada, 'Defence Energy and Environment Strategy (DEES) 2021-2022 Results Report', 7 October 2022, https://www.canada.ca/en/department-national-defence/corporate/reports-publications/dees/dees-2021-2022-results-report.html.

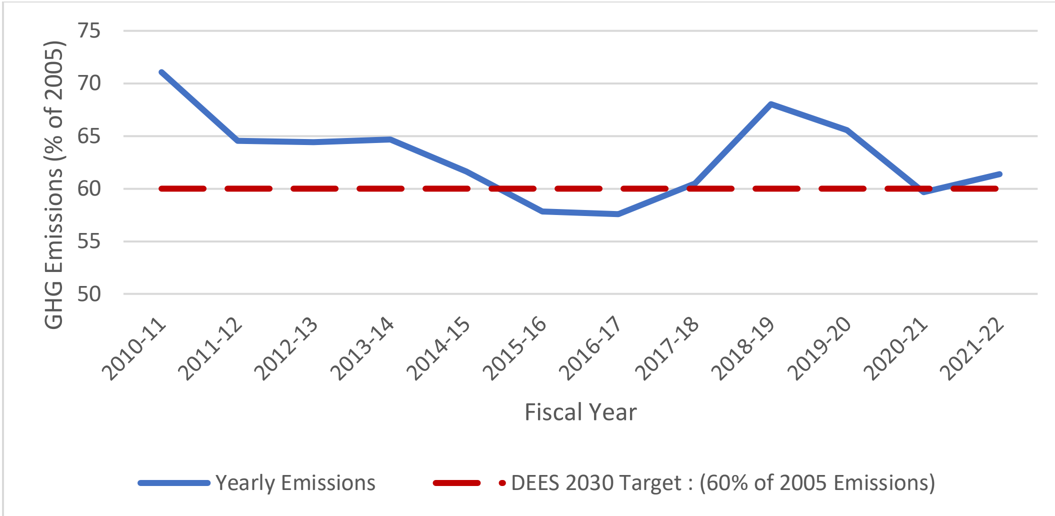


**Figure 4: Annual Greenhouse Gas Emissions by Fiscal Year as a percentage of 2005 emissions at DND 2010-2022.**

*Source: Complied by author from 'Government of Canada Greenhouse Gas Emissions Inventory'[39] dataset.*

With the less complex investments out of the way, getting to net-zero by 2050 will be far more challenging for DND to meet and will require significant investments into infrastructure. Canada has already the infrastructure for steam tunnels and heat distribution at many of its bases, making SMRs or MMRs an attractive option for both green heating and electricity production. From a basing perspective, Canada already has bases nearby many of its nuclear reactors, which could (given agreements), provide zero-emissions power to its bases on four sites. Table 1 summarizes the proposal in the Small Modular Reactor Feasibility Report and gives the proximity to the closest Canadian Forces Base (CFB).

| CAF Base | Distance | Date | Nuclear Power Site | Proposed Reactor Type |
|---|---|---|---|---|
| CFB Gagetown | 86km | 2030 | Point Lapreau | BWRX-300 |
| CFB Petawawa | 18km | 2026 | Chalk River | Ultra-Safe Nuclear MMR |
| CFB Borden | 83km | 2028 | Darlington | BWRX-300 |
| CFB Moose Jaw | 110km or 220km | 2032 | Elbow (proposed)<br><br>Estevan (proposed)[40] | BWRX-300 |

**Table 1: Selected Major CAF Military Installations within MOU provinces and their closest nuclear power generating station.**

*Source: Compiled by author and the Government of Ontario 'SMR Feasibility Report'[41]*

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[39] Treasury Board of Canada Secretariat and Treasury Board of Canada Secretariat, 'Government of Canada's Greenhouse Gas Emissions Inventory - Open Government Portal', accessed 19 April 2023, https://open.canada.ca/data/en/dataset/6bed41cd-9816-4912-a2b8-b0b224909396.

[40] SaskPower, 'Potential Facility Location', accessed 23 March 2023, https://www.saskpower.com/Our-Power-Future/Infrastructure-Projects/Construction-Projects/Planning-and-Construction-Projects/Planning-for-Nuclear-Power/Potential-Facility-Location.

[41] 'Small Modular Reactor Feasibility Report | Ontario.Ca'.

The Chalk River MMR additionally has the potential to advance technology in areas of defence and security interest. First Canada has committed to "developing low-emission electrical micro-grids at select installations in the High Arctic"[42], which MMRs could be a potential solution. Second, since MMRs can be relocated, they can contribute to Canada's core mission to "provide assistance to civil authorities and non-governmental partners in responding to international and domestic disasters or major emergencies"[43], by increasing the capacity to provide power and water in these disaster situations within a matter of days. Finally, Canada has heavily invested in its National Shipbuilding Strategy which will produce vessels for both the CAF and the Canadian Coast Guard for the coming decades[44]. While there is no explicit policy reason to develop nuclear propulsion for vessels at present, the technology and expertise in MMRs is transferrable to naval propulsion[45] which is an emergent area for the decarbonization of commercial shipping[46]. Development of nuclear propulsion is consistent with Canada's Industrial Technological Benefits strategy which identifies a 'clean technology' key industrial capability[47]. This may serve defence purposes if future requirements emerge, such as icebreakers or nuclear-powered submarines. While SSE does not recognize nuclear energy specifically, the advancements in the SMR licensing process and investments within Canada might allow the DND to leverage these investments for filling its own requirements.

## CANADIAN FOREIGN POLICY ON SMRS

As a signatory to the 1968 Non-Proliferation Treaty (NPT), Canada has committed to the peaceful use of nuclear energy as well as the non-proliferation and disarmament of nuclear weapons. The use of SMRs and MMRs remain consistent with the NPT, as well as Canadian nuclear policy which advocates for the exportation of Canadian nuclear resources (e.g., uranium) and technology. Canada began to invest heavily in the governance of SMR technology in 2022 to "strengthen international nuclear cooperation agreements; enhance domestic safety and security practices", and with the ultimate goal to "develop appropriate regulations for [SMRs] and to work with international partners on global regulatory harmonization"[48] so SMRs can be in turn safely exported. This collaboration is already happening bilaterally between Canada and US on licensing of current reactor designs. Canada has signed MOUs with the United States to pursue licensing and regulatory coherence over SMRs as their nuclear industries

[42] Government of Canada, 'Defence Energy and Environment Strategy', 8.
[43] Government of Canada, 'Strong, Secure, Engaged', 106.
[44] Public Services and Procurement Canada Government of Canada, 'About the National Shipbuilding Strategy - National Shipbuilding Strategy - Sea - Defence Procurement - Buying and Selling - PSPC', 13 April 2016, https://www.tpsgc-pwgsc.gc.ca/app-acq/amd-dp/mer-sea/sncn-nss/apropos-about-eng.html#a3.
[45] Black et al., 'Prospects for Nuclear Microreactors'.
[46] Samuel Furfari and Ernest Mund, 'Advanced Nuclear Power for Clean Maritime Propulsion', *The European Physical Journal Plus* 137, no. 6 (29 June 2022): 747, https://doi.org/10.1140/epjp/s13360-022-02980-5.
[47] Innovation Government of Canada, 'Key Industrial Capabilities', 23 April 2018, https://ised-isde.canada.ca/site/industrial-technological-benefits/en/key-industrial-capabilities.
[48] Government of Canada, 'Canada's National Statement on Nuclear Energy', para. 21.

are highly collaborative and interconnected[49], and therefore achieving a joint licensing scheme both improves the designs of North American SMRs as well as get them built on a faster and more cost-effective timeline.

Owing to the successful export of CANDU reactors, its position as a uranium exporter, and advocacy to maintain a stable NPT, Canada has established extensive diplomatic agreements on nuclear information sharing which will help establish the ties necessary to export SMRs. Canada remains a founding member of the Nuclear Suppliers Group and already has bilateral agreements or MOUs with 45 nations[50] which could serve as the basis for further agreements for technology transfer should SMRs be constructed. Canada is also the second largest producer of uranium and has the largest high-quality uranium reserves in the world [51] which in turn gives it a significant global influence and leverage for international trade and control of nuclear material.

The exportation of nuclear energy to other nations remains a key impetus for Canada's investments in SMR development. Canada sees a growing export market, particularly in South-East Asia for which Canada has declared its interest to grow economic ties in the Indo-Pacific Strategy, particularly in clean energy[52]. In the Association of Southeast Asian Nations (ASEAN), for example, nuclear is seen as part of the plan for clean energy transition in Indonesia, the Philippines, Thailand, and Malaysia, who all have plans to deploy reactors such as SMRs in the future as part of the Foundational Infrastructure for Responsible Use of Small Modular Reactor Technology (FIRST) program which also includes other regional partners South Korea and Japan[53]. While Canada may be the first to build a fully operational demonstration reactor in North America, the US has already announced a partnership with Indonesia to develop a NuScale SMR[54] which is currently in the licensing process in Canada, and a certified design in the US[55]. The Canada-US relationship at present is one of both one of cooperation and competition – cooperating over licensing regimes while trying to be

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[49] Canadian Nuclear Safety Commission, 'Sharing Our Expertise with the U.S. Nuclear Regulatory Commission: Signing of a Memorandum of Cooperation to Strengthen Regulation of Nuclear Safety', 15 August 2019, http://www.nuclearsafety.gc.ca/eng/resources/news-room/feature-articles/Sharing-our-expertise-with-the-US-Nuclear-Regulatory-Commission.cfm.

[50] Canadian Nuclear Safety Commission, 'International Agreements', 3 February 2014, https://nuclearsafety.gc.ca/eng/resources/international-cooperation/international-agreements.cfm#Euratom.

[51] Natural Resources Government of Canada, 'About-Uranium' (Natural Resources Canada, 6 July 2009), https://natural-resources.canada.ca/energy/energy-sources-distribution/uranium-nuclear-energy/uranium-canada/about-uranium/7695.

[52] Global Affairs Government of Canada, 'Canada's Indo-Pacific Strategy', GAC, 24 November 2022, https://www.international.gc.ca/transparency-transparence/indo-pacific-indo-pacifique/index.aspx?lang=eng#a1_3.

[53] ASEAN Centre for Energy, 'The 7th ASEAN Energy Outlook', 15 September 2022, https://aseanenergy.org/the-7th-asean-energy-outlook/; FIRST Program U.S. Department of State, 'Partners - Foundational Infrastructure for Responsible Use of SMR Technology (FIRST) Program', 5 April 2021, https://www.smr-first-program.net/partners/.

[54] U. S. Embassy Jakarta, 'United States, Indonesia Announce Partnership on Small Modular Reactor Nuclear Clean Energy', U.S. Embassy & Consulates in Indonesia, 18 March 2023, https://id.usembassy.gov/united-states-indonesia-announce-partnership-on-small-modular-reactor-nuclear-clean-energy/.

[55] 'NRC Certifies First U.S. Small Modular Reactor Design', Energy.gov, accessed 11 April 2023, https://www.energy.gov/ne/articles/nrc-certifies-first-us-small-modular-reactor-design.

early to establish supply chains on the international market for SMR exports. The visit of President Biden in March 2023 affirmed the start of such a partnership, and it was announced that Canada would join the FIRST program[56] which will allow for technology transfer from the US and reinforce the supply chain for SMR fuel worldwide. While Canada's inclusion into this multilateral deal is welcome, it does not address the larger question on what part Canada will play in the international export market for SMRs.

Since 2016, the US has revitalized its nuclear export industry, and has invested heavily in SMR technology, primarily to compete with aggressive Chinese and Russian investment and expansion[57]. The expansion of Chinese and Russian exports is problematic for the US, according to Miller and Volpe, as authoritarian regimes benefit from substantial state control over their nuclear industries which allows them to wield technology transfer and financing of projects as a means of power on the world stage[58]. As "China continue[s] to strengthen their grip on the nuclear market, they will have greater influence over the nonproliferation standards attached to nuclear transfers"[59] which have security implications for the US. In this context, Canada-US collaboration is more desirable as bringing significant economies of scale will increase the cost-competitiveness of western SMRs, and perhaps giving the US an advantage in US-China competition. In the rapid expansion of nuclear exports in the 1960s and 70s, there was little convergence between nuclear power producing nations on a single reactor design, but this national approach to nuclear power may no longer be viable in the face of increased competition with authoritarian states. With SMRs, achieving greater economies of scale will result in cost reductions, and owing to the significant demand for SMRs in both nations, further US-Canada cooperation is highly desirable for both nations should an equitable arrangement be reached.

## THE AUKUS PACT AND MARITIME PROPULSION

In 2021 the US, United Kingdom, and Australia signed a trilateral defence cooperation agreement which includes the technology transfer and construction of nuclear-powered submarines. One controversy is that these assets will not fall under the usual International Atomic Energy Agency (IAEA) inspection regimes that are used to prevent proliferation as military naval propulsion is excluded under the NPT[60], of which Australia is a signatory. Canada's exclusion from AUKUS may put any future decision to collaborate with the US to onshore nuclear technology for maritime propulsion purposes on shaky ground. Current SMR and MMR designs are not the same as the reactors

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[56] 'Backgrounder: Canada and the United States Advance Work to Grow Our Clean Economies and Create Good, Middle-Class Jobs on Both Sides of Our Border', Prime Minister of Canada, 24 March 2023, https://pm.gc.ca/en/news/backgrounders/2023/03/24/backgrounder-canada-and-united-states-advance-work-grow-our-clean.
[57] Nicholas L. Miller and Tristan A. Volpe, 'The Rise of the Autocratic Nuclear Marketplace', *Journal of Strategic Studies* 0, no. 0 (3 April 2022): 1–39, https://doi.org/10.1080/01402390.2022.2052725.
[58] Miller and Volpe.
[59] Miller and Volpe, 33.
[60] James M. Acton, 'Why the AUKUS Submarine Deal Is Bad for Nonproliferation—And What to Do About It', Carnegie Endowment for International Peace, accessed 19 April 2023, https://carnegieendowment.org/2021/09/21/why-aukus-submarine-deal-is-bad-for-nonproliferation-and-what-to-do-about-it-pub-85399.

powering US nuclear submarines, which use highly enriched uranium (HEU) fuel. HEU is particularly dangerous to proliferation as it does not require additional enrichment for weaponization. The use of HEU sets a dangerous precedent for non-P5 nations to add HEU maritime assets to their repertoire outside the safety of the NPT[61]. Canada has taken an aggressive stance on nuclear non-proliferation in the past, and if it were to require nuclear propulsion for its naval vessels in the future, it should look to technology that has a lower proliferation risk to be consistent with NPT treaty obligations by using low-enriched-uranium (LEU) and which could remain within the IAEA inspection regime.

In the future, Canada might wish to develop naval reactors using LEU. An example might be for a future fleet of heavy icebreakers. Canada is currently constructing replacements for its Coast Guard fleet, but climate change is likely to increase the need for such vessels[62] and a future requirement may require longer sustained operations without refueling. Canada will be in a position where it can develop this technology if it continues to maintain a strong nuclear industry, unlike Australia who is wholly reliant on US technology transfer as it does not presently generate nuclear power. This type of development is expensive, but one only needs to look to Australian domestic criticisms of the AUKUS deal to understand why pursuing domestic capabilities maybe worthwhile. Australia is faced with "uncertainty around the U.S.'s long-term commitment to the [Indo-Pacific] region; and uncertainty about the future political trajectory of the U.S"[63], which could change the power dynamics of the relationship to an unfavorable one over time should access to the Indo-Pacific be less of a priority. A second lower-cost option might be to partner bilaterally or multilaterally with nations such as those contributors to the FIRST program who already have strong nuclear industries: South Korea, Japan, and the US to develop such capabilities. This would allow Canada to develop nuclear propulsion vessels which are more consistent with the IPT as proliferation risks are reduced with LEU based fuel. In either case, there are some MMR technologies which could be applied to maritime propulsion, reducing development costs[64]. Whether such technology is perused by Canada or not, nuclear power is a candidate for the decarbonization of the maritime shipping industry, producing some future possibilities for economic benefits[65] so having the option to develop such technology is to Canada's advantage.

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[61] Acton.

[62] Canadian Coast Guard Government of Canada, 'Government of Canada Announces Polar Icebreakers to Enhance Canada's Arctic Presence and Provide Critical Services to Canadians', news releases, 6 May 2021, https://www.canada.ca/en/canadian-coast-guard/news/2021/05/government-of-canada-announces-polar-icebreakers-to-enhance-canadas-arctic-presence-and-provide-critical-services-to-canadians.html.

[63] Brendon O'Connor, Lloyd Cox, and Danny Cooper, 'Australia's AUKUS "Bet" on the United States: Nuclear-Powered Submarines and the Future of American Democracy', *Australian Journal of International Affairs* 77, no. 1 (2 January 2023): 45, https://doi.org/10.1080/10357718.2022.2163977.

[64] Testoni, Bersano, and Segantin, 'Review of Nuclear Microreactors'.

[65] Rupsha Bhattacharyya, Rami S. El-Emam, and Farrukh Khalid, 'Climate Action for the Shipping Industry: Some Perspectives on the Role of Nuclear Power in Maritime Decarbonization', *E-Prime - Advances in Electrical Engineering, Electronics and Energy* 4 (1 June 2023): 100132, https://doi.org/10.1016/j.prime.2023.100132.

## PROLIFERATION CHALLENGES WITH SMRS

SMRs and particularly MMRs present some new challenges to nuclear non-proliferation. For SMRs and MMRs, the current regulatory regime both domestically and internationally does not exist (particularly for mobile reactors) as their inspection and maintenance requirements are not yet well defined[66]. In response to this challenge, the IAEA has established a Regulators Working Group which is sufficiently active to be included in the IAEA Nuclear Harmonization and Standardization Initiative in August 2022[67]. This forum has been successful thus far at promoting cooperation amongst nations to identify and investigate regulatory challenges even between those who are competing for a share of the global SMR market.

The number of nuclear power sites should increase with SMRs and accordingly bringing with it additional concerns for physical security and transportation of fuel, waste, and equipment. Given the variety of designs, their associated tradeoffs, and site-specific considerations it is difficult to generalize absolutely on which aspects of security are most concerning. For example. many designs for MMRs also purport to have the ability for semi-autonomous operation[68] which can alleviate staffing issues but in turn exasperate security concerns on site. Since SMRs are modular, requiring transportation of material to and from manufacturing and refurbishment centers, the number of sites as well as the number of instances where fuel will be transported may increase. Black points out that these proliferation challenges are particularly acute for MMRs, and “revisions may be needed for international agreements on transport, security, safeguards, and safety to address microreactor technology”[69]. These revisions may challenge extant bilateral and multilateral nuclear cooperation agreements, requiring adjustments of those agreements coordinated by the IAEA, NSG, and others. The IAEA has recognized this challenge within the SMR Regulators Forum and “anticipat[es] that there may be challenges and changes needed to the legal and regulatory frameworks to enable effective regulation”[70].

Canada can work with other countries to promote international cooperation in the peaceful use of nuclear energy. Canada has been actively involved in initiatives such as the International Atomic Energy Agency (IAEA) and the Nuclear Suppliers Group (NSG), which promote peaceful nuclear technology transfer. Canada is well positioned to work within these multilateral regimes to strengthen regulatory frameworks for nuclear energy to ensure safety, security, and non-proliferation owing to its membership in the NPT, and strong regulatory framework for nuclear energy, and its nuclear safety and security standards are recognized internationally. Canada should advocate for changes to these agreements to better conform with SMRs. As SMRs are adopted by nations without

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[66] Wayne L. Moe, ‘Key Regulatory Issues in Nuclear Micro-Reactor Transport and Siting’ (Idaho National Lab. (INL), Idaho Falls, ID (United States), 1 September 2019), https://doi.org/10.2172/1616515; International Atomic Energy Agency, ‘Lessons Learned in Regulating Small Modular Reactors’, Text, *Lessons Learned in Regulating Small Modular Reactors* (International Atomic Energy Agency, 2022), https://www.iaea.org/publications/15149/lessons-learned-in-regulating-small-modular-reactors.

[67] ‘Small Modular Reactor (SMR) Regulators’ Forum’, Text (IAEA, 18 January 2018), https://www.iaea.org/topics/small-modular-reactors/smr-regulators-forum.

[68] Black et al., ‘Prospects for Nuclear Microreactors’.

[69] Black et al., 16.

[70] International Atomic Energy Agency, ‘Lessons Learned in Regulating Small Modular Reactors’, 3.

these strong regulatory frameworks and institutions, Canada can play a influential leadership role to help develop the appropriate institutions to ensure safety of SMRs. One critical issue as the industry gets established is the centralization of fuel-cycle facilities, as experts have noted “proliferation resistance would be enhanced by improving international safeguards and operating several multinational fuel-cycle facilities rather than supporting many more national facilities”[71]. Acknowledging that nations investing in SMRs will want to encourage growth in their respective industries, it will be challenging to find the appropriate balance of national growth with proliferation resistance through centralization of fuel and manufacturing facilities.

## THE RE-EMERGENCE OF CANADIAN NUCLEAR DIPLOMACY

The AUKUS deal has signaled a potential divergence between US and Canadian interests in the Nuclear Non-Proliferation Treaty (NPT). Muller describes this rift as one of identity in NPT norm entrepreneurship, the US has ‘conventional’ (security) concerns which dominate while Canada has ‘common-good’ (non-proliferation) concerns[72]. Although Canada is closely partnering with the US on developing a strong and coherent North American nuclear industry, this divergence could indicate a new partnership is needed between the two countries to achieve their objectives. Canada is pursuing nuclear power with low proliferation risks[73], but the US is seemingly prioritizing its strategic security interests in the Indo-Pacific such as through the AUKUS deal. In the past the “United States has always put nonproliferation above technological cooperation and disarmament”[74] signaling a departure from this stance. While there has been no formal disagreement on the matter of exporting US nuclear technology to Australia, as a proponent of the NPT there are risks that this transfer represents a dangerous precedence for P5 nations to export nuclear technology using HEU to NPT members using the maritime propulsion exclusion as a loophole.

The multipolarity of the world order is also likely to surface in nuclear diplomacy. Competition for the emerging SMR market may also serve to challenge the NPT, as some assert that “nuclear nonproliferation regime based around the NPT will likely be weakened by changes in the global distribution of power [as it will be] difficult for them to cooperate on expanding membership and enforcing the regime’s constituent agreements” [75]. This is problematic as the great powers seek to expand the countries that use nuclear power though SMR exports and ascribe to the NPT. It is likely that the norms

[71] Jonas Siegel et al., ‘An Expert Elicitation of the Proliferation Resistance of Using Small Modular Reactors (SMR) for the Expansion of Civilian Nuclear Systems’, *Risk Analysis* 38, no. 2 (2018): 242–54, https://doi.org/10.1111/risa.12861.
[72] Harald Müller and Carmen Wunderlich, ‘Not Lost in Contestation: How Norm Entrepreneurs Frame Norm Development in the Nuclear Nonproliferation Regime’, *Contemporary Security Policy* 39, no. 3 (3 July 2018): 341–66, https://doi.org/10.1080/13523260.2017.1394032.
[73] Louis-Benoit Lafontaine and Émile Lambert-Deslandes, ‘Canada’s Role in the New Nuclear Landscape’, *Network for Strategic Analysis (NSA)* (blog), 15 December 2021, https://ras-nsa.ca/canadas-role-in-the-new-nuclear-landscape/.
[74] Müller and Wunderlich, ‘Not Lost in Contestation’, 355.
[75] Rebecca Davis Gibbons and Stephen Herzog, ‘Durable Institution under Fire? The NPT Confronts Emerging Multipolarity’, *Contemporary Security Policy* 43, no. 1 (2 January 2022): 71, https://doi.org/10.1080/13523260.2021.1998294.

around nuclear technology will be challenged in this environment, and with it, Canada's ability to influence global nuclear policy and to shape international norms.

US-Canada cooperation in norm regulation around the exportation of nuclear technology and materials is not a new phenomenon. O'Mahoney demonstrates the compliance effect of Canada-US diplomacy in the wake of India's 'peaceful nuclear explosion' weapons test in 1974 where Canada and the US both used their respective diplomatic levers to convince NPT holdouts Korea, Italy, and Japan to sign the treaty soon after the test and impose suitable consequence to India[76]. The significance of the interconnectedness of the Canada and US nuclear industry implies that such bilateral cooperation could once again emerge in the export of SMR technology and fuel. Such cooperation will be necessary as US dominance is challenged by both Chinese and Russian SMRs exports. Notwithstanding this bilateral cooperation, Canada will still have its own influence to wield bilaterally with states developing regulatory regimes and institutions as SMRs are delivered to their countries, owing to Canada's stance in the NSG, its developed industry, participation in the NPT, and extensive repertoire of bilateral agreements. Canada remains the second largest exporter of uranium in the world, and 92.5% of raw imported uranium to the US[77] comes from Canada showing its importance globally and bilaterally. Canada's influence is distinct from the US and given its divergent interests in the NPT Canada has the opportunity to re-emerge as a leader in nuclear diplomacy.

## CONCLUSION

The energy security situation worldwide and renewed interest and investment in nuclear energy present Canada with several opportunities and challenges. Domestically, it is suggested that Canada consider expanding the scope of the SMR Action Plan to include defence and security interests presented in this paper in order to better capitalize on its investments and expand the possibilities of decarbonization, particularly using MMR technologies, at home. Canada is also presented with some challenges with SMR propagation throughout the world, on the one hand it is well-positioned to benefit from the expansion of nuclear energy as a producer of uranium and as an owner of a strong nuclear industry and institutions. On the other hand, the propagation of SMRs will challenge the non-proliferation regime that it has helped to steward for over 50 years. That the regime is now characterized as a multi-polar one will make careful statecraft necessary to carefully expand and use this influence – friend shoring with the US while promoting extant non-proliferation treaties and its own economic interests. The US-Canada bilateral relationship is of particular significance as Canada must navigate the US prioritization of Info-Pacific security and its apparent willingness use loopholes to export

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[76] Joseph O'Mahoney, 'The Smiling Buddha Effect: Canadian and US Policy after India's 1974 Nuclear Test', *The Nonproliferation Review* 27, no. 1–3 (2 January 2020): 161–79, https://doi.org/10.1080/10736700.2020.1803561.
[77] Energy Information Administration U.S. Government, 'Uranium Marketing Annual Report - U.S. Energy Information Administration (EIA)', accessed 26 April 2023, https://www.eia.gov//uranium/marketing/index.php.

HEU outside of the inspection purview of the IAEA while working cooperatively to expand the NPT and strong regulations for SMRs.

SMRs are poised to change the global energy landscape, as well as reinvigorate Canada's influence on the global stage in an area where it has waned in recent years. The expansion of SMRs presents Canada with an opportunity to grow its influence through normative entrepreneurship, helping the international community develop strong regulations for SMRs and to work with other nations on their own regulatory institutions.

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