THE UNIVERSITY OF BRITISH COLUMBIA

School of Public Policy and Global Affairs
Liu Institute for Global Issues
6476 NW Marine Drive
Vancouver, BC Canada V6T 1Z2

Phone 604 822 1558
ubc.sppga@ubc.ca
www.sppga.ubc.ca

To
Standing Committee on Science and Research
House of Commons
Ottawa
June 2022

Re: Study on Small Modular Nuclear Reactors

Thank you for providing me with this opportunity to speak with you. My name is M.V. Ramana and I teach at the School of Public Policy and Global Affairs, University of British Columbia. I carry out research on various technical and policy challenges associated with nuclear energy and small modular nuclear reactors (SMRs). I will focus my remarks on three topics: (1) potential markets for SMRs; (2) the potential for manufacturing and job creation from SMRs; and (3) the impacts of investing in SMRs on climate change mitigation.

1) At the very outset, I would like to emphasize that SMRs cannot solve all the problems confronting nuclear energy, especially the inability of nuclear power to compete economically with alternative sources of electricity. SMRs will be less competitive because they will be more expensive per unit of generation due to the loss of economies of scale.

2) Because of this adverse economics, there is little demand for SMRs. SMRs developed in Russia (KLT-40S design), China (HTR-PM design), and South Korea (SMART design—which was licensed for construction about a decade ago), have attracted no customers. In the United States, many utilities have exited the proposed NuScale project due to its high cost. Although many developing countries claim to be interested in SMRs, none have invested in the construction of one. Good examples are Jordan, Ghana and Indonesia, all of which have been touted as promising markets for SMRs for years, but none of which are buying one.

3) Niche markets, for example, remote mines and communities, are very limited. My research showed that even in a best-case scenario, remote mines and communities in Canada cannot provide the minimum demand necessary to justify investment in the factories needed to build these reactors.

4) A frequently heard argument for SMRs is that it will lead to jobs. This is misleading. The real question is whether such investment create more jobs than would be created by investing the same amount of money in other low-carbon energy technologies. The literature is unambiguous that nuclear reactor construction generates comparatively fewer jobs than renewables like solar and wind energy per dollar invested. Based on one recent study, I estimate that investing 1

billion US dollars in solar energy will create roughly 17000 job-years of construction related work, in onshore and offshore wind will create around 1200 and 3000 job-years, and finally less than 1000 job-years in nuclear energy. To the extent that SMRs are different from conventional large reactors, they will actually reduce the number of construction jobs created, by adopting processes such as modularization and factory manufacture. Finally, investing in building a product that has few customers can never lead to sustained employment.

5) SMRs will set back efforts to mitigate climate change for two reasons. First, there is an economic opportunity cost: money that is invested in SMRs would save far more carbon dioxide if it were invested in renewables and associated technologies. Second, no SMR will be constructed for at least another decade. This compounds the problem of the economic opportunity cost, in that the reduction in emissions from alternative investments would not only be greater, but also quicker.

I am happy to provide references for these statements, either from my work or that of others. Please feel free to email me if you need further information. You can contact me at m.v.ramana@ubc.ca.

With best wishes,

M. V. Ramana
Professor and Simons Chair in Disarmament, Global and Human Security
Director, Liu Institute for Global Issues
School of Public Policy and Global Affairs
University of British Columbia

Thank you for the opportunity to speak with you on June 16. I would like to follow up on some of the issues that were raised during the question and answer session and related topics.

1) One question asked was about the supply chain needed for a large deployment of SMRs, assuming that the financial unviability of this proposition can be ignored. The SMRs being considered for possible deployment in Canada in the foreseeable future all have one common feature: they are all very different from the CANDU reactor design that has dominated Canada's nuclear landscape. The designs I am referring to are the ARC-100, which is a sodium-cooled fast neutron reactor; the Micro-Modular Reactor (MMR), which is a high-temperature gas-cooled reactor; the BWRX-300, which is a light water reactor; and Moltex, which is a molten salt reactor. CANDU reactors use natural uranium as fuel. All the above mentioned SMR designs cannot operate with natural uranium fuel. The Micro-Modular Reactor and the BWRX-300 require low enriched uranium fuel, i.e., fuel where the uranium-235 isotope concentration is much more than what is found in nature. ARC-100 requires fuel with an even higher level of enrichment that is usually termed High Assay Low Enriched Uranium (HALEU). Finally, Moltex is fueled with a complicated salt of uranium, plutonium, and potassium.

None of these kinds of fuel can be produced in Canada currently, because there are no facilities to enrich uranium or reprocess spent fuel to produce plutonium. Therefore, these fuels, or the materials needed to fabricate them, must be imported from elsewhere. With the exception of the BWRX-300, which uses standard light water reactor fuel, all the other designs use fuels that have very limited commercial availability. In the case of HALEU fuel, for example, Russia is the sole commercial supplier today, and alternative sources will take a long time to start production at scale.[1] Given the events in Ukraine, there are clearly risks associated with using Russia as a source for such fuel. The fuel needed for Moltex has never been manufactured anywhere in the world, and the technical challenges to be overcome before doing so are great.

Developing domestic capacity to produce such fuels is also undesirable. The technologies for enrichment and reprocessing link the production of nuclear energy and the production of fissile materials that can be used to make nuclear weapons. The Canadian government has long supported the negotiation of a fissile material control treaty, which would likely impose constraints on countries acquire facilities to produce fissile materials. Canada has also supported measures to stop or limit Iran's enrichment of uranium, such as the Joint Comprehensive Plan of Action (JCPOA). Developing domestic uranium enrichment capacity will be at odds with these positions. Others have spoken to your committee about the problems associated with the pyroprocessing process associated with Moltex. I would like to highlight an open letter written by US nonproliferation experts and former government officials and advisors with related responsibilities.[2] Their concern was that by promoting plutonium extraction, Canada will undermine the global nuclear non-proliferation regime. In a subsequent letter, they also countered the arguments made by Moltex and explained why those were not justified.[3]

Thus, supplying the fuel needed to power these proposed SMRs is a major challenge and seeking to deal with those challenges by developing domestic capacity might be a case of a cure that is worse than the disease.

2) The other topic that came up during my session was the market for SMRs. I mentioned that the adverse economics of SMRs has meant that there is little demand for these products. I would like to buttress what I said with some evidence. As I mentioned, South Korea's main SMR design, the System-Integrated Modular Advanced Reactor (SMART), which is a 100 MW Pressurized Water Reactor, received a Standard Design Approval from Korea's Nuclear Safety and Security Commission (NSSC) in July 2012.[4] There have been no orders within South Korea. In 2017, the World Nuclear Association pointed out: "KAERI planned to build a 90 MWe demonstration plant to operate from 2017, but this is not practical or economic in South Korea".[5] The International Atomic Energy Agency's 2020 edition of its regular report on SMRs was candid about the high cost of construction when it stated that the "target overnight plant construction cost of a FOAK unit is $10000/kW(e) and an operating and maintenance cost of 2.8 ¢/kWh".[6] The high cost is likely the reason that in April 2021, Korea Hydro and Nuclear Power announced that it is "carrying out a project to improve the" SMART design, with the aim of obtaining "a license for the improved SMART by 2028".[7]

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[1] https://www.eenews.net/articles/how-russias-invasion-is-affecting-u-s-nuclear/ and https://www.energypolicy.columbia.edu/research/commentary/reducing-russian-involvement-western-nuclear-power-markets

[2] https://thetyee.ca/Documents/2021/05/26/OpenLetterNuclearFuelJustinTrudeau.pdf and

[3] https://npolicy.org/wp-content/uploads/2021/08/Second-Trudeau-Letter.pdf

[4] Kwon Dong-joon and Korea IT News, "Korean All-in-One SMR Won World's First Standard Design Approval," *Electronic Times Internet*, July 5, 2012, http://english.etnews.com/20120705200008.

[5] WNA, "Nuclear Power in South Korea," World Nuclear Association, February 2017, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

[6] See page 56 in IAEA, "Advances in Small Modular Reactor Technology Developments — A Supplement to IAEA Advanced Reactors Information System (ARIS) 2020 Edition," September 2020, https://aris.iaea.org/Publications/20-02619E_ALWCR_ARIS_Booklet_WEB.pdf.

[7] Jung Min-hee, "KHNP to Accelerate Development of Innovative SMRs," *Businesskorea*, April 20, 2021, sec. News, http://www.businesskorea.co.kr/news/articleView.html?idxno=65179.

For another example, consider the NuScale design, which is widely regarded as the closest to deployment in the United States, because it is the first SMR design to have received a final safety evaluation report (FSER) from the U.S. Nuclear Regulatory Commission.[8] The FSER is for a design with 50 MW modules and the application was submitted in 2016.[9] However, in a sign of the economic challenges it confronts, the output of the NuScale design has been increased from 50 MW to first 60 MW,[10] and then to 77 MW per module.[11] The output had already been increased multiple times.[12] NuScale would have to submit this new design details to the U.S. Nuclear Regulatory Commission for the uprate to be permitted.

In the meanwhile, the first NuScale project to be constructed in Idaho with electricity to be purchased by Utah Associated Municipal Power Systems has been reporting increased costs. In 2018, NuScale's estimated total cost was US$4.2 billion.[13] By 2020, that had jumped to US$6.1 billion; even though the U.S. Department of Energy had announced funding of up to $1.4 billion, at least eight municipalities withdrew from the project, and others cut the amount of electricity they were willing to commit to purchase.[14] As a result, the level of subscription to this project declined from 213 MW to 100.6 MW.[15]

The project was then scaled down to just six modules with a total power output of 462 MW (still vastly more than the subscription with no clear customer for the extra electricity), but the estimated cost came down only slightly, to US$5.32 billion.[16] Now, US$5.32 billion for 462 MW translates to US$11,515 per kilowatt of power capacity (this is an all-in estimated cost, not overnight cost). For comparison, the Vogtle project in the state of Georgia involves two AP1000 reactors that had a corresponding cost estimate, before construction started, of $14 billion for 2,234 MW of capacity, or around US$6,267 per kilowatt of power capacity. In other words, NuScale's estimated cost is around 80 percent higher than the corresponding cost of Vogtle when

[8] WNN, "NuScale SMR Receives US Design Certification Approval," September 1, 2020, https://world-nuclear-news.org/Articles/NuScale-SMR-receives-US-design-certification-appro.

[9] NuScale Power, "NuScale Submits First Ever Small Modular Reactor Design Certification Application (DCA)," January 12, 2012, http://newsroom.nuscalepower.com/press-release/company/nuscale-submits-first-ever-small-modular-reactor-design-certification-applicat.

[10] NuScale Power, "Breakthrough for NuScale Power; Increase in Its SMR Output Delivers Customers 20 Percent More Power," June 6, 2018, https://newsroom.nuscalepower.com/press-releases/news-details/2018/Breakthrough-for-NuScale-Power-Increase-in-Its-SMR-Output-Delivers-Customers-20-Percent-More-Power/default.aspx.

[11] Stephanie Cooke, "NuScale Moves to Larger-Scale Modules," *Nuclear Intelligence Weekly*, February 12, 2021.

[12] M. V. Ramana, "Eyes Wide Shut: Problems with the Utah Associated Municipal Power Systems Proposal to Construct NuScale Small Modular Nuclear Reactors," Small Modular Reactors (SMRs): News, Articles and Reports on Small Modular Nuclear Reactors (SMRs) (Portland, OR: Oregon Physicians for Social Responsibility, September 2020), https://www.oregonpsr.org/small_modular_reactors_smrs.

[13] Wendy Wilson, "Tough Economics for UAMPS Small Modular Reactors," *Snake River Alliance* (blog), April 11, 2018, http://snakeriveralliance.org/tough-economics-for-uamps-small-modular-reactors/.

[14] Sonal Patel, "Shakeup for 720-Mw Nuclear SMR Project as More Cities Withdraw Participation," *Power Magazine*, October 29, 2020, sec. Markets, https://www.powermag.com/shakeup-for-720-mw-nuclear-smr-project-as-more-cities-withdraw-participation/.

[15] UAMPS, "Carbon Free Power Project Resource 'Option' Update" (Los Alamos: Utah Associated Municipal Power Systems, February 16, 2021), https://losalamos.granicus.com/DocumentViewer.php?file=losalamos_7a21a2e19e64df6f2949137241f1d18a.pdf&view=1.

[16] Douglas O. Hunter, "Why the World Is Watching Utah's Carbon Free Power Project," *The Salt Lake Tribune*, November 23, 2021, https://www.sltrib.com/opinion/commentary/2021/11/23/douglas-o-hunter-why/.

construction started. Once construction started, Vogtle's cost skyrocketed and is now in excess of US$30 billion.[17]

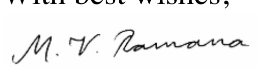
The bottom line: the costs of small modular reactors will be anything but small, when considered on a per unit of capacity basis. The power these might produce will definitely not be competitive with wind and solar energy.

3) We also reached the same conclusion when researching remote mines and communities in Canada, and we calculated that the cost of supplying power with an SMR to one of these could be *more than eleven times* that of the currently used diesel, but that the cost of a hybrid of wind power and diesel power could be a third lower than purely diesel power.[18] At these prohibitive costs, it is unlikely that there would be any market for SMRs in these communities. The only ones that might ever get built are projects largely or fully subsidized by the government.

It is worth asking oneself why the nuclear industry has talked about SMRs for remote mines and communities that are not otherwise served by the grid and that are currently electrified using diesel plants with very high fuel costs. This is because SMRs cannot benefit from economies of scale—the primary reason the nuclear industry started constructing larger nuclear plants in the first place. Hence, SMRs are even less economically viable for the electric grid than large reactors, which are themselves uncompetitive. There appear to be no viable large markets for SMRs.

I hope that these details help you in your deliberations. Please feel free to email me if you need further information. You can contact me at m.v.ramana@ubc.ca.

With best wishes,



M. V. Ramana
Professor and Simons Chair in Disarmament, Global and Human Security
Director, Liu Institute for Global Issues
School of Public Policy and Global Affairs
University of British Columbia

[17] David Schlissel, "Southern Company's Troubled Vogtle Nuclear Project" (Institute for Energy Economics and Financial Analysis, January 2022), https://ieefa.org/wp-content/uploads/2022/01/Southern-Companys-Troubled-Vogtle-Nuclear-Project_January-2022.pdf.
[18] 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 (2020): 111587, https://doi.org/10.1016/j.enpol.2020.111587.