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SUBMISSION TO THE CANADIAN NUCLEAR SAFETY COMMISSION REGARDING THE PROJECT DESCRIPTION FOR GLOBAL FIRST POWER'S MICRO MODULAR REACTOR

I am submitting this letter in response to the Canadian Nuclear Safety Commission's (CNSC) Updated Public Notice dated August 9, 2019, inviting comments on the Project Description of Global First Power's Micro Modular Reactor (MMR) Project at Chalk River. I have expertise and many years of experience in analyzing the safety and environmental impacts of nuclear power related facilities including Small Modular Reactors (SMRs). I have published several peer reviewed papers and reports on the topic. For a selection of my works, please see https://sppga.ubc.ca/profile/m-v-ramana/

Global First Power (GFP), the Project proponent, is proposing a Small Modular Reactor (SMR) project using MMR technology. There are several reasons to be concerned about a High Temperature Gas Cooled Reactor (HTGR) of the kind that GFP is proposing. Below, I describe two key issues: a history of poor performance and persistent problems in HTGRs that have been constructed and operated; and the potential for severe accidents that could result in the release of radioactive materials from the reactor and adversely affect the environment. The project description does not include any discussion of these problems. Finally, I list some key issues that are inadequately addressed in the proposal. Therefore, there should be a rigorous and comprehensive environmental assessment, and the public and independent inputs into the assessment should be sought, before the proposal moves any further.

History of Poor Performance and Persistent Problems

There is a long history of HTGRs that were constructed and operated, including two commercial HTGRs of the pebble type in Germany and two HTGRs of the prismatic type in the United States. There were also test HTGRs constructed and operated in the United Kingdom, Japan, and China. All these operating HTGRs underwent a wide variety of small failures and unplanned events, including ingress of water or oil, and fuel damage.[1] In all these reactors, graphite dust, typically contaminated with radioactive fission products, accumulated in the coolant circuit.

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[1] M. V. Ramana, "The Checkered Operational History of High Temperature Gas Cooled Reactors," *Bulletin of the Atomic Scientists* 72, no. 3 (2016): 171–79, https://doi.org/10.1080/00963402.2016.1170395.

Below, I briefly describe the many problems and disappointing performances of the prismatic type, which are similar to the proposed Micro Modular Reactor Project.

The first high temperature gas cooled reactor ever constructed was in the United Kingdom. Called Dragon, it was of the prismatic block variety. During its operational lifetime, Dragon faced a number of problems, especially with its heat exchangers. Although the tests conducted before the reactor was put into service gave "reassuring results", when the reactor was started up, it experienced "severe and rapid" corrosion on the water side of the heat exchangers, which resulted in the leakage of helium into secondary circuit.[2] Over just the first four years of operation, all six heat exchangers had to be replaced.[3]. The Dragon helium purification system also suffered a number of leaks.[4] The reactor only operated for about 12 years and the United Kingdom cut off funding because it envisioned no future for HTGRs in the country.[5]

The Peach Bottom reactor, another prismatic block design, was the first HTGR to operate commercially in the United States. It reached initial criticality in March 1966, but in October 1974, the plant's owners decided to shut down the plant because they considered it to be a financial drain. Over this short period, the plant had trouble with its steam generator, and the failure of multiple (nearly a hundred) fuel elements resulting in an increase in radioactivity in the primary cycle, a persistent problem that contributed to the decision to shut down the reactor.[6] Peach Bottom also experienced ingress of approximately 100 kilograms of oil into the reactor and the failure of the safety system that was to monitor moisture levels.[7]

Finally, Fort St. Vrain, the only commercial HTGR in the United States, was also of a prismatic block design. It reached criticality in January 1974, but was permanently shut down in August 1989. According to the Oakridge National Laboratory, which tracked the experience with the reactor for Nuclear Regulatory Commission, the reactor experienced 279 unusual events which included "29 water incursion events and failures of moisture detection systems"; "2 air or other unwanted gas incursion events and failures of gas detection systems"; " 3 fuel failures or anomalies"; and "2 failures or cracks in graphite, pipes, and other reactor structural

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[2] G. E. Lockett and R. A. U. Huddle, "Development of the Design of the High Temperature Gas Cooled Reactor Experiment" (Winfrith, UK: Organization for Economic Co-Operation and Development, 1960), http://inis.iaea.org/Search/search.aspx?orig_q=RN:10488097; G.E. Lockett and S.B. Hosegood, "Engineering Principles of High Temperature Reactors," in *Symposium on Advanced and High Temperature Gas Cooled Reactors* (Jülich, Germany, 1968).

[3] P. S. Gray and C. Watts, "Operating Experience with Dragon Reactor" (Symposium on Advanced and High Temperature Gas Cooled Reactors, Jülich, Germany, 1968).

[4] J. M. Beck, C. B. Garcia, and L. F. Pincock, "High Temperature Gas-Cooled Reactors Lessons Learned Applicable to the Next Generation Nuclear Plant" (Idaho Falls, Idaho, USA: Idaho National Laboratory, September 2010), http://www.osti.gov/scitech/biblio/1023461.

[5] Walter C. Patterson, *Nuclear Power* (Harmondsworth, UK: Penguin Books, 1976), 39.

[6] James L. Everett III and Edward J. Kohler, "Peach Bottom Unit No. 1: A High Performance Helium Cooled Nuclear Power Plant," *Annals of Nuclear Energy* 5, no. 8–10 (1978): 321–35, https://doi.org/10.1016/0306-4549(78)90017-8.

[7] Beck, Garcia, and Pincock, "High Temperature Gas-Cooled Reactors Lessons Learned Applicable to the Next Generation Nuclear Plant"; R. D. Burnette and N. L. Baldwin, "Primary Coolant Chemistry of the Peach Bottom and Fort St. Vrain High-Temperature Gas-Cooled Reactors," in *Specialists Meeting on Coolant Chemistry, Plate-out and Decontamination in Gas-Cooled Reactors, Juelich, Germany; 2 - 4 Dec 1980* (Vienna, Austria: International Atomic Energy Agency, 1981).

components"; all of this just between 1981 and 1989.[8] Some of these, especially the incursions of moisture, have significant implications for the plant's safety. Another problem was a series of fluctuations of the core temperature.[9] On the whole, its lifetime load factor was a mere 15.2 percent—in other words, it produced less than a sixth of the electricity it would have generated had it operated at full power even during the few years when it was considered operational. Because of this remarkably poor performance, no U.S. utility has ever since considered ordering an HTGR. This in complete contrast to the mid-1970s, when Fort St. Vrain was being put into service; at that time, U.S. utilities were considering constructing up to ten HTGRs.[10]

Potential for Accidents

The operational experiences of HTGRs have implications for safety. It is evident that HTGRs are prone to a wide variety of small failures and thus one should not presume that reactors, such as the proposed Micro Modular Reactor, will actually operate as described in design documents. The real world experience will likely be significantly different from what is advertised. Further, any of these failures could be the trigger for larger failures or accidents, with an array of more severe consequences.

The two chief accident sequences that are significant at HTGRs are the ingress of air or water into the reactor core.[11] Both of these could lead to radiation doses to nearby populations under some circumstances. Although these accident sequences have been the subject of extensive research,[12] there are still significant questions about the safety of HTGRs that have not been answered satisfactorily, especially in light of the experience with the HTGRs constructed so far.

The safety concern associated with air ingress results from the potential for the graphite (carbon) used as the neutron moderator to react with the air that has entered the reactor; the combination of air and hot graphite could result in a variety of chemical reactions and physical effects leading to deterioration of the fuel and possible radioactivity releases. Unlike the RBMK reactor in Chernobyl, where graphite burning started only after some delay, HTGRs are hotter and the operating temperatures are higher than the ignition temperature of graphite (600 to 700 °C).[13] As a result, burning of graphite could occur immediately in the event of a major air ingress. Further,

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[8] ORNL, "Fort Saint Vrain Gas Cooled Reactor Operational Experience" (Washington, D. C.: Nuclear Regulatory Commission, 2003).

[9] H. G. Olson, H. L. Brey, and D. W. Warembourg, "The Fort St. Vrain High Temperature Gas-Cooled Reactor: X. Core Temperature Fluctuations," *Nuclear Engineering and Design* 72, no. 2 (1982): 125–37, https://doi.org/10.1016/0029-5493(82)90209-6.

[10] Harold M. Agnew, "Gas-Cooled Nuclear Power Reactors," *Scientific American*, June 1981; Bruce K. McDowell et al., "High Temperature Gas Reactors: Assessment of Applicable Codes and Standards" (Pacific Northwest National Laboratory, October 31, 2011), http://www.osti.gov/scitech/biblio/1031438.

[11] Matthias Englert, Friederike Frieß, and M. V. Ramana, "Accident Scenarios Involving Pebble Bed High Temperature Reactors," *Science & Global Security* 25, no. 1 (2017): 42–55, http://dx.doi.org/10.1080/08929882.2017.1275320.

[12] J Wolters et al., "The Significance of Water Ingress Accidents in Small HTRs," *Nuclear Engineering and Design* 109, no. 1–2 (1988): 289–94; W. Kröger, J. Mertens, and J. Wolters, "Basic Risk Analyses for High-Temperature Reactors," *Nuclear Engineering and Design* 121, no. 2 (July 2, 1990): 299–309, doi:10.1016/0029-5493(90)90115-E; Lohnert, "The Consequences of Water Ingress into the Primary Circuit of an HTR-Module - From Design Basis Accident to Hypothetical Postulates"; Zheng, Shi, and Wang, "Water-Ingress Analysis for the 200 MWe Pebble-Bed Modular High Temperature Gas-Cooled Reactor."

[13] Ibid.

HTGRs, like other reactors, also have other inflammable materials and as such other fires are possible; for example, on 3 October 1987, Fort St. Vrain suffered from "a relatively severe turbine building fire" due to the burning of oil used in the hydraulic system, which "impacted control room habitability".[14] Such fires could add to the potential for radioactive release.

Because air ingress has to begin with a break, there will be a ready pathway for any radionuclides within the primary circuit to escape. Further, the heat generated during the oxidation process results in buoyancy forces that could provide the impetus for radionuclides to escape into the atmosphere and be transported till relatively higher altitudes. In short, a severe air ingress accident could lead to the escape of significant quantities of radionuclides, although for the reasons described below it is difficult to estimate the potential source term.

Ingress of water could result not just in chemical reactions between water and graphite, but also in an increase in the reactivity of the system because of the additional moderating influence of water on neutrons. The ingress of water into a reactor is not a purely theoretical concern. In May 1978, about 30 tons of liquid water did enter the core of the AVR reactor in Germany. The situation was made worse by human error since operators did not treat the water ingress with sufficient seriousness, continuing to operate the reactor at low power for several days.[15]

Missing Information

The Project Description provided by GFP does not provide several basic details needed to understand the potential environmental and social consequences of the project. I will list a few examples, but I would like to emphasize that these are by no means a complete list.

- There is a mention of the citadel building, but it is not clear if this is to be considered an airtight containment and what kind of overpressures it is capable of withstanding in the event of an accident.
- The project description says that the TRISO fuel to be used will use low enriched uranium. But it does not even mention what the level of enrichment (3 percent, 5 percent, or 19.9 percent) and where this fuel will be procured from. Canada does not enrich uranium.
- The project description describes TRISO fuel as "highly proliferation resistant". But it has been known for decades that TRISO fuel can be reprocessed and plutonium separated from the spent fuel.[16] There have been recent developments that make this task even easier.[17] Therefore, this description cannot be taken at face value.
- More generally, uranium enrichment is a sensitive technology and is one of the linkages between nuclear energy and nuclear weapons programs. Therefore, any evaluation of the project must include a comprehensive and thorough assessment of the proliferation risks

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[14] S. P Nowlen, M. Kazarians, and F. Wyant, "Risk Methods Insights Gained From Fire Incidents," NUREG/CR-6738 & SAND2001-1676P (Washington, D.C.: Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, 2001), A14–12.

[15] Moormann, "A Safety Re-Evaluation of the AVR Pebble Bed Reactor Operation and Its Consequences for Future HTR Concepts," 29.

[16] R. G. Wilbourn, "Solvent Extraction in HTGR Reprocessing. Interim Development Report II" (San Diego, CA: General Atomic Co., July 1, 1978), https://doi.org/10.2172/6567661.

[17] Liyang Zhu et al., "Uranium Extraction from TRISO-Coated Fuel Particles Using Supercritical CO2 Containing Tri-n-Butyl Phosphate," *Journal of Hazardous Materials* 241–242 (November 30, 2012): 456–62, https://doi.org/10.1016/j.jhazmat.2012.09.072.

posed by the project. A special concern is the incompatibility between the use of enriched fuel and the Canadian government's advocacy for a fissile material control treaty and its efforts to stop Iran's acquisition and expansion of uranium enrichment technology.

- The project proposal also lacks a detailed discussion of dealing with the radioactive spent fuel that the MMR will produce. It just says: "Once the Adaptive Phased Management (APM) plan has been commissioned by the Nuclear Waste Management Organization (NWMO) in preparation for final disposal in a Deep Geological Repository (DGR), the reactor vessel will be opened, and the graphite blocks containing the used fuel (i.e., fuel elements) will be transferred to the DGR. The NWMO will determine what adaptations, if any, are required for the current used fuel containers to safely contain and isolate the MMR used fuel elements, while also meeting regulatory requirements". This is unsatisfactory for two reasons. (1) The APM plan has been devised to deal with spent fuel from currently operating and shut down Pressurized Heavy Water Reactors. The discussions that led to the APM proposal suggest that the repository that is sought to be constructed will not have the capacity to deal with new reactors. Thus, it is incorrect to assume that the NWMO can deal with future waste streams from reactors such as the MMR. At the very least, the NWMO must issue a comprehensive evaluation of waste from the proposed reactor project before this reactor is evaluated. (2) There are significant differences between spent fuel from a HTGR and from other kinds of reactors.[18] Because the waste form in reactors like the MMR will include a large amount of graphite, the volume of waste generated will be greater than the PHWR on a capacity basis.

For all these reasons, I submit that there should be a rigorous and comprehensive environmental assessment of the MMR project before the proposal moves any further. Further, in view of the complete absence of experience with HTGRs in Canada, the assessment should involve inputs from independent experts around the world.

Please feel free to email me if you need any further information. You can contact me at

With best wishes,

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[18] Paul E. (Paul Edward) Owen, "Waste Characteristics of Spent Nuclear Fuel from a Pebble Bed Reactor" (Thesis, Massachusetts Institute of Technology, 1999), https://dspace.mit.edu/handle/1721.1/9548.