

Navigating the Challenges of Small Modular Reactors: A Comprehensive Study of Site Design, Policy, Economics, and Community Integration in Canada's Nuclear Energy Transition

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Summary

Nuclear energy is positioned to have an important role in Canada's energy transition as a low-carbon alternative. Small Modular Reactors (SMRs) have been proposed for meeting the demands of remote communities and mine sites where few other options are readily available. For both on- and off-grid applications, SMRs have been shown to be an economically viable alternative to diesel generation [1] and are described as a clean, safe, and affordable energy solution [2]. Some key issues not yet addressed in regulatory documents include considerations for site safety and security within small communities, nuclear waste storage, as well as site design, operation life, and decommissioning in various geographic, geologic, and social settings across Canada [3].

This study aimed to address the outlined key issues of a preliminary policy and site design framework by conducting a case study. The study assessed the existing Chalk River Laboratory project, which is the first commercial deployment of an SMR in Canada [4], on a potential future SMR location. Additionally, possible sites for future SMRs lie near the "Ring of Fire" mineral deposit. The Indigenous communities in the area have an anticipated base load of 7 MW, while the Ring of Fire system has the potential to reach a demand of 60+ MW due to mining activities [1]. Due to the large but variable electrical demand of the communities and mining operations, the Ring of Fire acts as an ideal case study. Figure 1 depicts the approximate location of the case study area, focused around the "Ring of Fire" mineral deposits in Northern Ontario.

The case study featuring Chalk River and the Ring of Fire was carried out by addressing three topics. The first topic identified the problems related to nuclear safety, site security, and nuclear waste for SMR implementation in remote communities. The second topic determined the site-specific issues that may be presented by a facility located near the Ring of Fire and multiple Indigenous communities. Finally, the design of the SMR at Chalk River was assessed on how well it addressed concerns from both technical design and policy standpoints. The design critique focused on guidelines which implement 'safety-' and 'security-by-design' concepts using structure design. In addition, considerations were given to how the design addressed on-site nuclear waste storage in the short- to medium-term, prior to decommissioning. Further policy examinations were given to existing Indigenous communities, who may take a large element of power in the planning and monitoring of the project, prioritizing collaboration between project proponents and community leaders. These examinations included economic policies that provide a suitable environment for investment, the minimum governance policy requirements, regulation of decommissioning and nuclear waste,

as well as the integration of Indigenous communities into the project [5]. Recommendations were given to where gaps in regulation and policy exist and how they could be addressed based on the case study results.

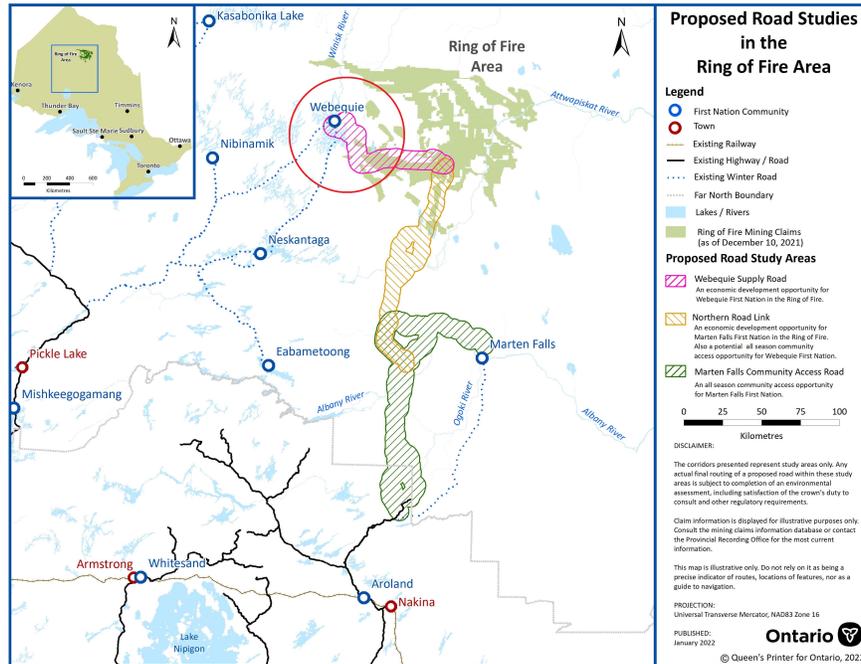


Figure 1: Overview of the Ring of Fire Area and the approximate study site location (red circle). Figure modified from [6].

Theory / Method / Workflow

The implementation of SMRs in the Ring of Fire area of Northern Ontario is an opportunity to provide clean, reliable, and affordable energy to the region. However, it also presents various challenges and concerns related to nuclear site design and the perspectives of the local communities potentially affected by these projects. To assess the feasibility of SMRs in the region, it was crucial to identify and address these potential regulatory, safety, and environmental issues. In this context, the Ontario Ministry of Energy conducted a feasibility study on SMR deployment [1], while the Canadian Nuclear Safety Commission (CNSC) published a discussion paper on the regulatory strategy, approaches, and challenges related to SMRs [3].

This research project aimed to build on these existing studies and contribute to a deeper understanding of the challenges and opportunities involved in SMR development in Northern Ontario. The problem statement for this study was to identify and analyze the key regulatory issues, including safety, security, waste management, Indigenous involvement, and policy considerations that could impact SMR deployment in the region.

The following three research questions have been developed to guide the analysis:

1. What are the specific problems related to nuclear safety, site security, and nuclear waste for SMR implementation in Northern communities?
2. What additional site-specific issues are presented by the Ring of Fire site?
3. How does the SMR design at Chalk River address these problems?

The first research question outlined issues related to site design in SMR implementation in northern communities in Ontario. This question served as a study of the discussion paper published by the Canadian Nuclear Safety Commission [3,4], which identified many key issues regarding the physical safety and security of SMR design in Canada. The results of this study shed light on the Chalk River design, and provided insight into social and Indigenous impacts of the design choices. The second research question focused on any other site-specific issues surrounding the Ring of Fire site. This question acted as a study of the Ring of Fire Subsystem, and aimed to identify specific site concerns that may not be adequately addressed by the potential 'fleet implementation' of SMRs with similar site designs and layouts [5]. The analysis of the social impacts of the site considered issues that may be raised by social groups and highlighted the importance of involving Indigenous communities in the planning, development, and operation of SMRs [7].

The third research question was centered on how the SMR design at Chalk River project [3] addressed the problems identified in the first two questions [4]. The results of this question showed how the proposed SMR design did or did not address concerns related to nuclear safety, site security, and waste management. This analysis also offered potential improvements to both Chalk River and Ring of Fire site designs.

Through this research project, we aimed to provide valuable insights and recommendations that could inform the development of a feasible, sustainable, and socially responsible SMR implementation strategy in Northern Ontario.

Results, Observations, Conclusions

As Canada moves closer towards the implementation of SMRs, there are still challenges to be overcome. This study highlighted key gaps in the regulatory framework surrounding the implementation of SMRs for remote sites considered to be edge-grid or off-grid. Preliminary results from this study indicated several important issues related to nuclear safety, site security, and nuclear waste that must be addressed. This study explored the potential social impacts of SMR implementation, particularly in relation to Indigenous communities in Canada, building on previous research and policy discussion [7, 8].

Discussions presented by the Canadian Nuclear Safety Commission [3] highlight the key design issues from a regulatory standpoint. Additional site-specific issues presented by the Ring of Fire site [9, 10] underscored the need for a more nuanced design approach that addresses local concerns and considers Indigenous involvement. The analysis of the SMR design at Chalk River highlights the progress made through safety- and security-by-design, while showing there are still gaps that need to be addressed. The study highlights these gaps and provides commentary on potential avenues that could be taken to address them. While some issues can be addressed through design, many roadblocks towards SMR deployment stem from primarily social concerns that cannot be treated through design alone. These types of concerns must be integrated into the regulatory

documents carefully to ensure that Indigenous voices are not ignored. These insights are in line with previous studies on Indigenous involvement in energy projects, the role of circular economy in energy infrastructure projects, and the challenges of measuring attitudes towards nuclear power in Northern communities. Building on these observations, further research can lead to meaningful conclusions on the potential benefits and concerns of SMR implementation, as well as strategies to ensure Indigenous communities are involved in decision-making processes [5, 7].

Novel/Additive Information

Parcels of land around the Ring of Fire are owned and resided upon by the Marten Falls and Webeque First Nations. Both of these groups requested roads to be built into the area in 2018 [11, 12]. This would increase accessibility such that it is not restricted to certain times of year, which is currently the case with winter roads [13, 14]. Additionally, roads into the area would allow increased opportunity for some of the many claims on mineral deposits in the area to be developed [15]. For communities throughout the area, increased accessibility and secure power generation would provide more comfort throughout the year as well as opportunities to be involved in multiple resource projects. Nuclear energy would complement the potential mines as well as increase the quality of life of many communities in the area.

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