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Energy Geotechnics for Remote Canadian Arctic Applications[1]

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Abstract. Climate change will affect all reaches of the globe. The most susceptible regions must adapt first by employing new sustainable technologies and strategies. Canada's North is particularly susceptible to effects of climate change, which will cause a 0.2-1.2ºC increase per decade. Temperature anomalies, which have been detected globally since 1880 are magnified at upper latitudes, which includes the Canadian Arctic. Canada has nearly 300 remote communities and resource-based businesses (usually mines) that rely on locally produced heating and electricity. Reliable power for remote communities is critical for sustainable life in the Canadian Arctic. Power demand for communities and commercial operation ranges from a few hundred kilowatt-hours to tens of megawatt-hours. Currently many communities and commercial operations rely on fossil fuel generation to electricity and hot water demands. The vast majority of these systems have reached their design life or will within the next decade. What will be the method of choice for the next generation of power generation? Should we continue to burn fossil fuels or consider other options? This extended abstract examines energy geotechnics questions of using small modular reactors to meet the current and future power demand for the range of remote Canadian communities in the arctic.

Keywords. Energy Geotechnics, arctic, permafrost, small-modular-reactors.

1. Extended Abstract

Climate change will affect all reaches of the globe. The most susceptible regions must adapt first by employing new sustainable technologies and strategies. Canada's North is particularly susceptible to effects of climate change, which will cause a 0.2-1.2ºC increase per decade [1]. Temperature anomalies, which have been detected globally since 1880 are magnified at upper latitudes [2]. Rising air temperatures will cause a subsequent increase in ground temperatures and degradation of permafrost, which is ground that is frozen for two consecutive years [3]. Permafrost landscape is susceptible to climate change effects due to its ice content. Melting of the ice component leads to significant ground loss including subsidence, thaw slumps, and irreversible changes to the landscape.

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Reliable energy is a fundamental requirement for sustainable communities. Canada has nearly 300 remote communities and resource-based businesses (usually mines) that rely on locally produced heating and electricity. Power demand for communities and commercial operations ranges from a few hundred kilowatt-equivalent to tens of megawatt-equivalent [4]. Currently many communities and commercial operations rely on fossil fuel generation to electricity and hot water demands. To meet this demand, communities and businesses have relied on high-priced fossil fuel-based power plants. However, most of the current generation plants have reached their design life or will within the next decade, which increases maintenance and operational costs. Fuel transportation and storage take up much of these costs as well as risk of unreliability and efforts are being made to reduce reliance on fossil fuel generators [5]. During this time of power generation renewal, the opportunity exists to consider other modes of power and heat generation.

Canada's remote utilities and communities are spread across the country, but they share common challenges with respect to power availability and use. The first and biggest challenge is meeting the community's peak electrical power demand. Local policy limits expansion since once a community reaches 75 to 85% of its prime-rated power capacity it must stop permitting new connections to its local grid [5]. The adverse effects associated with refusing new connections are reduced standard of living through over-crowded housing and reduced economic opportunity because of the inability to create more grid connections without running the risk of a blackout. The second challenge is limited access to fuel. Many remote communities in northern Canada lack year-round-access and are only accessible by plane, ship, or by truck during the winter months. Responding to the lack of connectivity, communities are forced to purchase and store large inventories of fuel, which increases both economic costs and environmental risks. The third challenge is high generation cost, which follows from the second challenge. With poor economies of scale for small community power plants and the use inefficient diesel gensets, operational and maintenance costs of these power plants is considerably higher than for other similar types of power plants. The final challenge is periodic but timely, as it arises from the aging of existing fossil fuel-based infrastructure. Environment and Natural Resources Canada reported that most of the diesel generating infrastructure in Canada's north have already reached their life expectancy or will within the next decade [4]. Continuing to use aging plants increases already high operation and maintenance costs. For example, in Nunavut, of the 25 diesel power plants operating, 10 have life expectancies that end around 2026, and the remaining 15 have already exceeded their expected end-of-life [5].

During this time of renewal all power options should be considered as replacements for the current fossil-fuel focus. Initially this multi-disciplinary research focusses on assessing feasibility of deploying small modular nuclear reactors (SMRs) for remote settlements, utilities, and armed forces bases. As summarized in a SMR feasibility report [6]:

- SMRs are competitive economically against diesel genset technology. For remote mine scenarios, potential savings are of up to $152/MWh.
- SMRs reduce production of greenhouse gases in long-term projects.
- SMR production, use, and implementation have the potential for direct impact on Canada's economy with widespread use.

When determining the feasibility of the SMR technologies, primary generation concerns are related to technology readiness and its ensuing regulatory framework. With the Canadian Small Modular Reactor – SMR Roadmap [7], Canada has initiated the process of assessing technology readiness and changing its regulatory framework to be inclusive to new Generation IV reactors that are atypical of current designs. The SMR roadmap has begun bringing representatives from industry, governments, utilities, and enabling partners together to develop the vision for the next wave of nuclear innovation in Canada to follow in the footsteps of the world-renowned Canadian Deuterium Uranium (CANDU) technology.

From an energy geotechnics perspective, foundational aspects of deploying SRMs in remote arctic applications takes on primary importance. Remote communities lie on various permafrost landscapes from continuous to sporadic. Permafrost landscape is, on its own, susceptible to climate change effects. Infrastructure constructed in permafrost adds complexity to the ground-climate interaction. Problems associated with infrastructure founded in permafrost include differential settlements, accelerated melting, and damage to infrastructure. Thus every structure founded on permafrost from buildings to linear infrastructure is subject to effects of climate change. SRMs magnify the challenge due to their being an inherent heat source and their strict differential settlement limitations.

The second phase of this research employs computational and physical modelling methodologies to examine sustainable foundations for SRMs deployed in the arctic. The studies will model heat and moisture movements in typical permafrost profiles for the range of permafrost and ice content zones. Computational model results show the effect of SRM heat profile on foundation stability. Future models will consider the combined effect of climate change on SRM foundations in the range of permafrost zones and ice contents.

Reliable power for remote communities is critical for sustainable life in the Canadian Arctic. Power demand for communities and commercial operation ranges from a few hundred kilowatt-hours to tens of megawatt-hours. Currently many communities and commercial operations rely on fossil fuel generation to electricity and hot water demands. The vast majority of these systems have reached their design life or will within the next decade. What will be the method of choice for the next generation of power generation? Should we continue to burn fossil fuels or consider other options? This paper will examine energy geotechnics questions of using small modular reactors to meet the current and future power demand for the range of remote Canadian communities in the arctic.

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