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A REVIEW OF SMALL MODULAR REACTORS: THE CANADIAN APPLICATIONS AND IMPACTS

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1 Objectives

There has been significant effort worldwide to develop small modular reactors (SMRs) as emissions-free, economically competitive alternatives to large nuclear power plants or fossil-fired plants. SMRs are defined as nuclear power reactors with a standardized modular design and an electrical output of less than 300 MWe. Due to recent advances, some SMR technologies have reached a point where deployment in the next decade is quite likely.

The objectives of this paper are to: (1) understand the driving force behind SMRs, their benefits and design requirements; (2) review Canada's presence in SMR development; (3) identify unique applications for SMRs in Canada; (4) consider the economic impact of an SMR industry in Canada.

2 Significance

Nuclear energy can be used to produce electricity, to provide steam for industrial applications and for district heating while producing virtually no greenhouse gas emissions. Historically, nuclear power plants faced significant barriers to entry into the electricity market related to their large capacity and high capital cost. Recent advances in SMR technology could see some concepts ready for deployment within the next decade. These new SMRs boast improved safety, simpler operation and potentially greater reliability. These characteristics, along with economic competitiveness, may allow SMRs to replace fossil-fired plants in some applications in Canada in the near future.

3 Theory

Small reactors have been built for research, industrial, space and military applications since the inception of nuclear energy technology in the 1950s. Following some of the early test reactors, the first small nuclear reactor was built in the United States to power a nuclear submarine: the USS Nautilus.

As an alternative to the large nuclear power reactors currently operating, factory-built SMRs are being considered for nuclear power production, as well as district heat and industrial steam applications. The proposed SMRs can potentially supply power incrementally as the demand increases (therefore, the initial capital cost can be reduced), or to locations that are far away from the electrical grid systems that currently have few alternatives to fossil-fired plants.

4 Design and Procedure

Although many of the following objectives are shared across SMR designs, the design concepts used to achieve them vary widely depending on the level of innovation. Normally the more innovative the concept, the more research and development is required to achieve the objectives.

Nearer-term concepts will not fully meet all of the design objectives below, however they could be available in five to ten years as they are based on demonstrated reactor technologies. Longer-term concepts, that use exotic fuels and/or coolants, could more fully meet the design objectives below, but will require 15+ years of research and development, including a prototype, prior to deployment.

The following design objectives are common across SMR concepts, with varying degrees of implementation depending on the level of innovation.

Ease of Construction – By standardizing modular plant design, SMRs are expected to achieve economies of scale in all aspects of siting, design, construction, and operations. This is facilitated by: (1) the simplifying design, (2) factory construction for improved productivity, and (3) compact design for delivery of pre-fabricated components to the site reducing the time required for installation.

Ease of Operation – Many innovative SMR concepts incorporate remote control and operation, as well as off-site refueling to reduce the need for highly specialized experts at remote sites. Some innovative SMR concepts have refueling intervals of 20+ years, which would substantially reduce fuel handling transactions, minimizing non-proliferation and terrorist threats.

Safety and Security – Safety and security is of utmost priority for SMRs concepts that are located in remote locations. Because of their low power, SMRs can be designed to be inherently safe, meaning that the reactor can be shutdown and cooled without external power or a separate cooling tower/lake. The reactor is also required to be secure, robust enough to withstand natural and human-produced events.

Reliability – SMRs would benefit from load following capabilities in self-contained locations to ensure the reliability at varying levels of demand. Redundancy must also be incorporated to ensure there are no reliability issues if the SMR is taken off-line without notice.

Transportability - Some of the most innovative SMR concepts are also considering the requirement of transportability, allowing the SMR to be moved to alternate sites and/or be brought back to the factory for refueling, during its operational life.

5 Findings

5.1 Canadian Presence

Canada is in a rare situation with a vast land area, low population density, rich natural resources and difficult-to-reach arctic communities. Many off-grid locations could benefit from an alternative power source as well as from the steam production that could be used for heating and industrial applications. However, the power output of leading SMRs, of between 50 and 300 MWe, is too large for many smaller Canadian applications. With several provinces seriously considering SMRs for future deployment, and no well developed Canadian SMR option, a number of vendors have been promoting very small modular reactors (vSMR, < 50MWe) in Canada.

Potential unique Canadian applications for SMRs and vSMRs being considered are: mining, remote communities, and arctic sovereignty (military facilities).

5.2 Canadian Applications

5.2.1 Mining

In 2012, Canada's mineral production was valued at $52.6 billion, employing 418,000 workers at 1,264 mines across the country, and 5,500 people in R&D [1]. The Mining Association of Canada identified that "Improving energy efficiency and reducing greenhouse gas emissions are priorities for the Canadian mining industry to limit impacts on the environment and to help reduce operational costs at a mine site." This is partially driven by the anticipated introduction of new greenhouse gas emissions regulations for the industry by the federal government [1].

Overall, Canada's mining sector is expected to grow at an average of 1.9% per year until 2035 [2], a total of 50% and equivalent to 650 new mines. If SMRs were used to produce electricity and/or industrial steam at some of these locations, greenhouse gas emissions could be significantly reduced. For example, crude oil production is one potential mining application where SMRs could be very well suited. The Conference Board of Canada predicts that bitumen production, through new in situ extraction sites that rely on high-temperature steam to separate the bitumen prior to extraction, will increase by 2.09 million barrels per day [2]. An average 50,000 barrels per day site requires approximately 20 MWe and 500 MWth [3]. Therefore, approximately 850 MWe and 20,900 MWth must be installed to support nearly 43 new in situ bitumen extraction sites.

SMRs, particularly vSMRs that are transportable, could produce the electricity required by in situ mines with virtually no emissions to the environment, while producing the high quality steam needed to extract the bitumen from the oil sands.

5.2.2 Remote Communities

Canada has a number of remote communities located in the Yukon (5), the Northwest Territories (26) and Nunavut (25) that are powered by diesel generators [4,5]. Each community is self-contained, relying on a 1 MWe diesel generator for electricity and district heating [6]. This is significantly less than the power required by industrial applications, therefore it will be difficult to apply a single vSMR technology for industrial and public use.

Additionally, remote communities can be difficult to access, have short construction seasons due to harsh winters, and have limited ability to attract and retain highly skilled personnel. Therefore, the innovative requirements being incorporated in some vSMR concepts, such as remote control and operation, are necessary for deployment in remote communities. As a result, SMRs are not likely to be deployed in remote communities for 15+ years.

5.2.3 Arctic Sovereignty and Military Facilities

Canada's north has strategic value as a source of natural resources and a valuable trade route from/to Atlantic ocean to/from Pacific ocean. The melting of Arctic ice is making the Northwest Passage an increasingly attractive trade route. Canada considers this route its own and has named it the "Canadian Northwest Passage" in 2009. Introducing nuclear icebreaker and nuclear submarine technologies, as well as increased Canadian presence would help maintain Canada's sovereignty rights in this region.

5.3 Economic Impact

Regardless of the SMR concepts deployed, an SMR industry in Canada would significantly impact the economy. Physically, significant infrastructure is required to support the industry. In addition, highly skilled personnel would be required to support the research and development, construction, and operation of the SMRs.

The required facilities would cost billions of dollars to construct, creating thousands of jobs during construction, and hundreds during operations. In addition, Canada could also export SMRs to other countries with similar needs. These exports would create additional manufacturing jobs, and opportunities for international collaborations in research and development as well as regulation.

Additionally, the Canadian Chamber of Commerce found that "The lack of economical and environmentally-sound energy options is one of the most serious challenges for businesses, especially in communities which are off-grid." [7] Deploying SMRs in these communities would improve the attractiveness of these areas for development. The increased economic production would result in other community improvements to support employees such as: clean drinking water, housing, and health care [7].

6 Conclusion

If the SMR technology progress continues at its present rate, larger SMRs based on demonstrated technologies will be ready for deployment within the next 5 to 10 years and could be used to provide power and steam to larger, less remote, industrial and mining applications in Canada. These SMRs could provide an emissions-free, cost effective alternative to current fossil-fired plants, but would not be well suited for some unique Canadian applications.

However, larger SMRs have too great of a power output to provide economical electricity/heat to off-grid communities and they do not offer the remote operation capabilities required by some sites. Smaller versions of SMRs would better match the power demand at these sites. Some less innovative designs, which are based on demonstrated technologies, may potentially be ready for deployment within the same 5 to 10 year time-frame. Other advanced SMRs proposed for remote off-grid sites use innovative technology that has not yet been demonstrated on a commercial scale. These SMRs will likely need 15+ years to deploy in order to develop the necessary knowledge and practical operating experience necessary to finish research and development, demonstrate the technology and overcome licensing uncertainties.

Regardless of the SMR technologies ultimately selected, an SMR supply chain would bring significant value to Canada through GDP, jobs, and exports.

7 References

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